AIRCRAFT SURVIVABILITY

Published by the Joint Aircraft Survivability Program Office

SUMMER 2008

JAS
JOINT AIRCRAFT SURVIVABILITY PROGRAM

SPACE Survivability— Time to Get Serious

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2008**	2. REPORT TYPE	3. DATES COVERED **00-00-2008 to 00-00-2008**

4. TITLE AND SUBTITLE **Aircraft Survivability: Space Survivability - Time to Get Serious, Summer 2008**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **JAS Program Office,200 12th Street South,Crystal Gateway #4, Suite 1103,Arlington,VA,22202**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**32**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Aircraft Survivability is published three times a year by the Joint Aircraft Survivability Program Office (JASPO) chartered by the U.S. Army Aviation & Missile Command, U.S. Air Force Aeronautical Systems Center and U.S. Navy Naval Air Systems Command.

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After the Challenger disaster, the National Aeronautics and Space Administration (NASA) established the Office of Safety, Reliability, and Quality Assurance (SR&QA) to repair the "lack of independent safety oversight." Later, after the tragic Columbia accident, NASA conducted an in-depth investigation to identify causes of the accident and set forth recommendations to save the program's future. The Columbia Accident Investigation Board (CAIB) reported considerable concern over the lack of a crew escape system and an ability to address worst-case scenarios and emergencies.

Among diagnostics for ballistic testing at the Service survivability labs, optical methods have played an important role as tools to establish success or failure of the test or to determine the sequence of events. This has been accomplished through video imaging—acquiring a series of pictures of the test sequence to determine the times and locations of important events. However, it may be beneficial to use some of that light in a different way. The intensity of light emitted from thermal and reactive events, integrated across the image area and recorded over time during the test, has the potential to tell us much more about what is happening.

The Joint Aircraft Survivability Program Office (JASPO) is pleased to recognize Mr. Greg Czarnecki for Excellence in Survivability. Greg is an aircraft survivability team leader in the Aerospace Survivability and Safety Flight, 780th Test Squadron, 46th Test Wing. Greg, a native of South Bend, Indiana, enlisted in the Navy in 1972 and served four years as an Operations Specialist. Upon completion of active duty, he joined the Naval Reserves and began undergraduate studies at the University of Dayton.

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by CAPT Ken Branham, USN

New Joint Test Director, Joint Live Fire-Aircraft Systems

Welcome aboard to CAPT Ken Branham, United States Navy (USN). He joined the Joint Aircraft Survivability Program (JASP) in October 2007 as the Military Deputy Program Manager. As of January 2008, he was assigned additional duties as Joint Test Director (JTD) for the Joint Live Fire-Aircraft Systems (JLF-Air), relieving John Murphy from the 46th Test Wing, who held the mantle superbly for many years.

CAPT Ken Branham, USN

CAPT Branham received his B.S. in Chemical Engineering from the University of Rochester, NY, in 1982 and his M.S. in Acquisition and Logistics from the Air Force Institute of Technology (AFIT), Wright Patterson Air Force Base (WPAFB), in 1991. He was commissioned as an Aerospace Engineering Duty Officer (Maintenance) through the Aviation Officer Candidate School (AOCS) in Pensacola, FL, in 1983. His active duty assignments included VF-154, Black Knights, an F-14 squadron at Naval Air Station (NAS) Miramar, CA; Aircraft Intermediate Maintenance Department (AIMD), NAS Key West, FL; graduate school at AFIT, WPAFB, Dayton, OH; and VFA-86, Sidewinders, an F/A-18 squadron stationed at NAS Cecil Field, FL. He completed four extended deployments aboard the USS *Constellation* and USS *America*.

After leaving active duty, CAPT Branham held several jobs in engineering management in the Atlanta, GA, area for companies such as Amerada Hess and Marriott Management Services. Maintaining his Navy roots, he drilled as a selected reservist in Atlanta with the USS *Enterprise* (CVN-65) Augment Unit, Naval Air Warfare Center (NAWC) 0167, and Naval Air Systems Command (NASC) 1376, where he was Executive Officer for 2 years.

CAPT Branham is no stranger to the aircraft survivability arena. He has been a member of the Navy Joint Combat Assessment Team (JCAT) for the past 3 years, drilling with the NASC 0766 unit out of Patuxent River, MD. In April 2006, he was mobilized to fulfill his JCAT role in Iraq, stationed with the 3D Marine Aircraft Wing (MAW) Forward out of Al Asad in support of Operation Iraqi Freedom (OIF 05-07). He also established the JCAT Det in Balad to provide greater JCAT support to the U.S. Army. This effort enabled greater access to aircraft incidents nationwide and access to much needed survivability data. While in theater, he also achieved his Fleet Marine Force Officer designation. Welcome aboard CAPT Branham!

JCAT News…From the Front

The Joint Combat Assessment Team (JCAT) Forward Team continues to solidify connections and expand the benefits of our work to customers across the multi-country theater. To this end,

CDR Robert Mark settles into his new surroundings at Al Faw Palace, Camp Liberty, Baghdad.

LCDR Nordel and LT Bussell get a "taste" of an Al Asad dust storm (no camera lens filter used)

CAPT Kirby Miller's 1-year focused effort at MNC-I resulted in a major success—the U.S. Central Command (CENTCOM) approval of a JCAT Request for Forces (RFF). This RFF means that six multi-service JCAT deployers will be a core requirement for all future CENTCOM conflicts. CAPT Miller obtained final approval on his last day of work at Al Faw Palace. CAPT Miller received a Bronze Star from the U.S. Army (approved by the Naval Air Systems Command [NAVAIR]) for his significant in-theater contributions during the past year. CDR Robert Mark relieved CAPT Miller as JCAT Liaison Officer (LNO) on 9 February 2008.

To further enhance our services to the aircrew engaged in the daily counter-insurgency fight, CDR Askin (JCAT Forward office in charge [OIC]) decided in early February to establish a JCAT presence in northern Iraq at Mosul. This decision has significantly improved the completeness of aircrew and intelligence data, enhanced the quality of battle damage photos, and shortened the final report turnaround time. U.S. Air Force 1st Lt "James" Stephenson is very busy on point in Mosul for the JCAT Forward Team.

CDR Askin put the finishing touches on a solid tour in country with the completion of a comprehensive OIC turnover folder. While serving in Al Asad, Iraq, he was responsible for day-to-day JCAT operations and administratively responsible for all six forward deployed JCAT personnel. For his exceptional service, CDR Askin was awarded a Meritorious Service

Medal by the 2d Marine Aircraft Wing (Forward) Commanding General. LCDR Steve "Nordo" Nordel assumed CDR Askin's duties as JCAT OIC (Forward) on 30 January 2008.

LCDR Mark Roach continues to make a positive impact on the quality of our report products working with Task Force 49 in Balad. He has personally written or reviewed more than 21 reports since arriving in theater in last November. LT Steve Bussell relieved LCDR Roach as the JCAT Balad OIC on 10 March 2008.

LCDR Nordel gets a tour of Iraq with VAQ-142.

Under LCDR Nordel's leadership, the JCAT Forward Team has focused on improving access, quality, and timeliness of the JCAT Forward information. To this end, JCAT has solved the U.S. Only/NOFORN SIPRNET access issue by creating a new JCAT website. This website is available to all in-theater U.S. personnel and all continental United States (CONUS) based team members. For the uniform resource locator (URL) for this site, please contact CAPT Ken Branham. This site now hosts not only all 206 OIF JCAT final reports but also reference information for current and projected in-theater aviation units.

JASP FY08 Joint Program Review

The Joint Aircraft Survivability Program Office (JASPO) will host its 2008 Joint Program Review (JPR) at Nellis AFB, NV, from 16–18 September 2008. The meeting will be held in the Threat Training Facility, Building 470. This review will facilitate dialogue on aviation survivability between the S&T, acquisition, and operational communities and industry by presenting a technical overview of JASP FY08 projects and informing the aviation community of JASP efforts.

The JASP mission is to increase the affordability, readiness, and effectiveness of tri-service aircraft through the joint coordination and development of survivability technologies and assessment methodologies. The 2008 annual program review will cover current JASP projects addressing aircraft susceptibility reduction, vulnerability reduction, survivability assessment, the JLF-Air program, and JCAT. The review is an excellent summary of JASP efforts in 2008 and an opportunity to network with government, including not only active duty military and civilian employees but also industry leaders in aircraft survivability. Last year, roughly 130 survivability community members attended.

At this writing, it is still early in the planning process, so the agenda has not been set and the registration website has not been generated. That information will be distributed when available. As an example of a typical agenda, the previous program review began with an intelligence overview, an update concerning foreign armor developments, and a JCAT presentation. Forty-nine project briefings were presented on susceptibility reduction, vulnerability reduction and survivability assessment, and eight JLF-Air projects were briefed. An instrumentation roundtable brought together instrumentation technicians from the three services' test ranges, test engineers, application engineers, image analysis software developers, and optical component manufacturers to discuss ways of improving the use of high-speed imaging for ballistic survivability testing.

The review is classified SECRET/NOFORN and is open to U.S. Government personnel and contractors who have a need to know. For further information, please contact Darnell Marbury in the JASP office.

Missile Engagement Threat Simulator

As a follow-up to the Man-Portable Air Defense Systems (MANPADS) Launcher (MPL) discussed in the spring edition of the *Aircraft Survivability* magazine (see News Notes), we will now introduce you to the Navy's version. The NAWC, Weapons Division, and the Weapons Survivability Laboratory at China Lake, CA, developed the Missile Engagement Threat Simulator (METS). METS evolved from a previous program: Missile Intercept Kinetic Energy System (MIKES). An early assumption was that an aircraft's absorption of kinetic energy of inert missile components (*e.g.*, rocket motors, fins, fuze, control section, seeker) substantially augmented the missile's kill mechanism. Operation Desert Storm demonstrated that inert testing that was performed did not match well with actual combat encounters. Consequently, MIKES was modified to allow a capability to launch MANPADS with live warheads. Thus, METS was born.

METS is a single-stage cold gas gun that uses compressed nitrogen as its propelling mechanism and can fire a simulated MANPADS (rocket motor fuel has been replaced, and missile fins have been modified as part of the fuzing mechanism) at various speeds up to 1,800 feet per second. The gun is remotely filled, fired, or unfilled from a fire control building (safe area). The firing mechanism used is based on a differential pressure fast-acting valve. Nitrogen is initially filled into an inner chamber and pressurizes, causing a floating piston to seal the outer chamber from the atmosphere. Once sealed, nitrogen is then introduced into the outer chamber and filled to the specified firing pressure. The gun is fired by venting the inner chamber (trigger), which causes the pressurized gas in the outer chamber to force the piston back and allow the gas to escape out of the barrel, thus propelling the MANPADS down range.

A significant challenge was to develop a fuzing mechanism that could withstand the high g loads of the immediate acceleration. Developing an exploding bridge wire (EBW) fuze was required. The missile EBW fuze uses a custom 3,000-volt screen system to provide proper current and voltage to reliably detonate the warhead on impact to the target. Voltage is passed from the screens through the modified missile fins through the detonation sequence. Grounding issues had been identified during the aircraft skin penetration testing. To remedy this problem, the detonator is now isolated from the missile body.


Successful METS Shot 20 February 2008

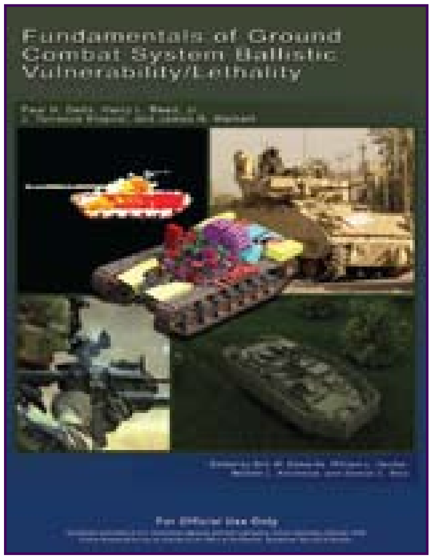
METS not only provides a capability to evaluate the vulnerability of aircraft to the MANPADS threat at an existing live fire test and evaluation (LFT&E) facility but also allows for fully instrumented realistic testing on fully operational aircraft operating at full power with up to 500-knot airflow over the aircraft structure with hit point accuracy within inches in a controlled test environment. Performing these tests at the Weapons Survivability Laboratory allows the utilization of more than 200 channels of data collection, 10 high-speed film cameras, 15 video cameras, High-Velocity Airflow System (HIVAS) (520 knots airflow) and firefighting (CO_2, Aqueous Firefighting Foam [AFFF]) capability to extinguish fires generated during test shots. Damage can be inspected after testing if structures are saved from fire. Programs supporting this effort are Joint Strike Fighter (JSF), Multi-Mission Maritime Aircraft (MMA), JCAT, and JASPO.

Fundamentals of Ground Combat System Ballistic Vulnerability/Lethality (Soon To Be Published)

The Director of Operational Test and Evaluation, U.S. Army Research Laboratory, SURVICE Engineering Company, and Survivability/Vulnerability Information Analysis Center have announced the pending publication of the book *Fundamentals of Ground Combat System Ballistic Vulnerability/Lethality*. With contributions from more than 50 vulnerability and lethality (V/L) professionals in government and industry, the 300-page "V/L book" provides a comprehensive look at the foundational history, terminology, processes, tools, and applications associated with the V/L discipline. The publication will serve as not only a textbook for new V/L analysts, testers, developers, researchers, and scientists but also a ready-reference for practitioners already working in the field.

The V/L book's major themes are—

- History of V/L analysis
- Role of V/L in materiel design, development, and acquisition
- V/L analysis process
- Missions and means framework
- Initial representation
- Damage mechanisms
- Component dysfunction
- Personnel vulnerability
- Wound ballistics
- Target response
- Tactical utility
- Vulnerability assessment



- Measures of effectiveness
- Fault trees and degraded states
- Networked systems
- Modeling and simulation tools and methods
- Verification, validation, and accreditation (VV&A)
- System acquisition and life cycle
- Vulnerability reduction
- Tactics and doctrine

Also included are an extensive bibliography and appendices that provide more in-depth discussions on fragment penetration, behind-armor debris characterization, P(CD|H) estimation, and applied VV&A processes.

The book is undergoing final approval and printing, with distribution through SURVIAC expected this summer. To reserve a copy, please contact A. J. Brown (SURVIAC). Reservations, as well as technical questions regarding the book, may also be directed to Eric Edwards (SURVICE).

Ken Goff Passes the Baton to Randy Short

Ken Goff, who has been the Navy JASP Principal Member for almost five years, has passed the baton to Randy Short, who is the current Director of the NAVAIR Survivability & Lethality Division. Ken is the former Director of the Survivability Division who is now the Director of NAVAIR's newly established Anti-Tamper Division. Ken has been in the Survivability Division at NAVAIR since he graduated from college in 1984 and was promoted to Division Director in 1997. Ken has been the Survivability Division's R&D Program Manager, Survivability Team Leader for a number of systems over the years, including the F/A-18E/F, F-35, CH-60F, CH-53E, MV-22, and others, and the NAVAIR Chemical/Biological/Directed Energy Warfare Focal Point. The NAVAIR Survivability Division has been a leader in LFT&E for all Navy/Marine Corps air platforms (rotary and fixed wing aircraft) and will now also support all Air Force fixed wing aircraft since the recent BRAC decision. Ken strongly supported the establishment of the Joint Combat Assessment Team to provide excellent ties to the warfighter through their combat data collection activities in Iraq. Ken also served as the Chairman of the JASP Principal Members Steering Group for several years. We all appreciate Ken's Survivability contributions to NAVAIR, the JASP, and the warfighter and wish him the very best in his new position. Thanks, Ken.

Ken Goff

Space Survivability—Time to Get Serious

by Mathias Kolleck

It is time to get serious about space survivability. China's recent actions have demonstrated their anti-satellite (ASAT) capabilities, marking a turning point in how the United States should view space. In August 2006, China "painted" or illuminated American intelligence satellites flying over its territory using ground-based high-power lasers. The Chinese were either trying to blind the spacecraft with their laser or testing whether their laser could guide a direct ascent kinetic energy ASAT. On 17 January 2007, the Chinese followed up this action by using a kinetic kill vehicle launched by a medium-range ballistic missile to destroy an inactive Chinese Fengyun-1C weather satellite. The destruction of this satellite was by far the most severe satellite break-up ever in terms of identified debris, generating more than 1,500 large scraps (4 inches or larger) of debris. The Chinese had made two prior unsuccessful attempts, at least one of which occurred last year. In both instances, the Chinese interceptor boosted into space but missed the target. The reentry vehicles later fell back to Earth.

The problem of spacecraft protection is complex and difficult. Current spacecraft are typically not protected against manmade threats, not because spacecraft are easily replaceable or unimportant, but simply because our potential adversaries did not have the technological capabilities to threaten our spacecraft. Space was a sanctuary. The Chinese tests have now definitely changed this thinking. In his opening address to the Air Force Association's Annual Air Warfare Symposium on 8 February 2007, Secretary of the Air Force Michael Wynne remarked, "Space is no longer a sanctuary."

When considering the hostile threat environment, note that our space systems face a larger number of threat types than our air systems. Manmade threats include laser and kinetic energy ASAT weapons demonstrated by the Chinese; orbital debris (considerably augmented by the Chinese destruction of their satellite on-orbit); communication link threats (electronic interference and electromagnetic impulse [EMP] caused by an exoatmospheric nuclear detonation); and ground element threats (from terrorist attacks or sabotage). Space systems also face natural threats: meteoroids, solar storms, and atomic oxygen (molecules from Earth's extreme upper atmosphere impacting spacecraft surfaces).

To enhance the survivability of our spacecraft, the same basic survivability concepts applied to aircraft for many years can be employed. Aircraft and spacecraft survivability are functions of susceptibility and vulnerability. Susceptibility is the system's inability to avoid being hit by a threat in a hostile environment. Typical susceptibility reduction concepts are as follows—

- Threat warning
- Noise jamming and deceiving
- Signature reduction
- Expendables
- Threat suppression
- Weapons and tactics.

Vulnerability is the system's inability to withstand damage caused by the threat that it could not avoid. Typical vulnerability reduction concepts are as follows—

- Component redundancy, with separation
- Component location
- Passive damage suppression
- Active damage suppression
- Component shielding
- Component elimination.

These basic concepts can be applied to aircraft and spacecraft. Noise jamming and deceiving apply equally well in both environments, as does threat suppression. Any type of active defense can protect the on-orbit satellite and the ground element and communications links of the entire space system. Spacecraft susceptibility reduction also can be achieved by providing the on-orbit satellite with some type of maneuver capability (spacecraft tactics). The ability to change orbit will allow a spacecraft to avoid being hit by large pieces of orbital debris and meteoroids and help defeat accurate foreign tracking and orbit determination. The ability of foreign countries to accurately track and determine the orbits of U.S. space assets is one of the biggest threats to U.S. space systems, as the Chinese demonstrated in their 17 January test. However, providing this on-orbit tactical capability will come with a cost: an additional fuel requirement.

Reducing a spacecraft's vulnerability involves the same fundamental concepts as hardening an aircraft. Systems are developed that are more tolerant of the many and varied threat effects. Component redundancy with appropriate separation applies to air and space systems. For space systems, the ability to have a constellation of satellites provides an opportunity to dramatically

use this particular vulnerability reduction technique. Because space systems are even more sensitive to weight considerations than aircraft, techniques such as component shielding and damage suppression typically do not extend to the space arena, although a cost-benefit analysis of specific situations might indicate that such techniques would be appropriate.

The Defense Advanced Research Projects Agency (DARPA) has taken a first step to address these potential issues described above through its Orbital Express (OE) Advanced Technology Demonstration Program (ATDP). On 8 March 2007, the OE was successfully launched and achieved low earth orbit (LEO). The OE consisted of two satellites—

1. A prototype servicing satellite (ASTRO), equipped with a robotic arm, and
2. A surrogate next generation serviceable satellite (NextSat). Figure 1 illustrates ASTRO and NextSat.

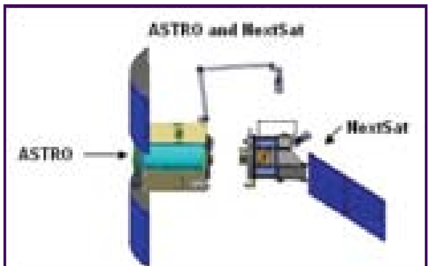


Figure 1 ASTRO and NextSat (Graphic courtesy of DARPA and Boeing)

The goal of this ATDP was to validate the technical feasibility of robotic, autonomous on-orbit refueling and reconfiguration of satellites. Refueling satellites will enable frequent on-orbit maneuvering to improve coverage, change arrival times to counter denial and deception, improve survivability, and extend satellite lifetime. Electronics upgrades on-orbit can provide regular performance improvements and dramatically reduce the time to deploy new technology on-orbit.

The ATDP was successfully completed on 29 June 2007, when the ASTRO servicing spacecraft autonomously rendezvoused with NextSat from a distance of 7 kilometers. Once within range, ASTRO's robot arm grabbed NextSat and docked together the two satellites after a brief intervention by ground controllers to correctly align the docking ports. ASTRO then used its arm to transfer a spare battery between the satellites and transfer propellant. Figure 2 illustrates the NextSat spacecraft from ASTRO. Originally, the Pentagon had planned to decommission ASTRO and NextSat after the 29 June rendezvous; however, this action was delayed to give the military's senior leadership additional time to consider extending the mission.

Figure 2 NextSat Spacecraft as Seen From ASTRO (Graphic courtesy of DARPA)

The research paper, "Star Tek—Exploiting the Final Frontier: Counterspace Operations in 2025," presents possible future susceptibility and vulnerability reduction techniques. This paper identified the need for counterspace operations and provided numerous highly advanced concepts to reduce the susceptibility and vulnerability of future systems.

From a susceptibility aspect, advanced threat warning systems consisting of gravity gradiometers are possible. Gravity gradiometers are instruments and systems that detect mass density contrasts. Recent gradiometer research has focused on sea-based submarine detection applications. With multiple gradiometers located on multiple satellites on-orbit, approaching "foreign bodies" can be detected passively. Data and measurements gathered could be combined with data from other detection devices to enhance detection and even identification probabilities. This effort will determine appropriate follow-on defensive reactions. To be used in a space detection mode, the gravity gradiometer detection system must be able to detect an object of roughly 100 kilograms (kg) at a range of about 100 nautical miles.

A second potential future threat warning and jamming technology is the space interdiction net. Total battlespace awareness will be the key to any future counterspace operations. The space interdiction net will detect satellite transmissions, pinpoint the source of those transmissions, and identify the end user of the information. This capability is required to selectively deny information to an adversary from his own military or commercial system. In addition, a space interdiction net will be able to determine whether damage to a U.S. satellite is the result of malicious action or natural causes (*e.g.,* solar flare or meteoroid impact). The space interdiction net will consist of an orbiting grid of satellites capable of continuous coverage of Earth and will use a web of interlinked microsat systems to radiate a very low power force field over the entire globe. The field that this constellation will generate will act as a blanket around Earth and will be able to detect any energy penetrating the blanket, seek out the desired signal, and jam or degrade the important portion of the signal. This force field will be able to pick up transmissions in a wide range of frequencies and will use triangulation from three or more satellites to pinpoint the source.

In the future, stealth will be taken to a new level as a susceptibility reduction technology. To date, stealth has been a passive activity aimed at minimizing reflection and maximizing the absorption of energy, with the goal of reducing the amount of energy reflected back to the sender. On the other hand, this new technology, called cloaking, will use active means to enable a satellite, as seen by enemy sensors, to blend into any environment (*i.e.,* become invisible). This satellite cloaking system will operate on all space assets that are critical to U.S. operations, including military and key civilian spacecraft. The cloaking system will go into action once alerted by its onboard sensor array or warned by its command and control network. Initially, the system will classify the incoming detection signal as radar, infrared, or visual. Sensor information is passed to the nanocomputer control system, which relays commands to the nanobuilding blocks in the satellite skin. These building blocks, acting as their own molecular assembly lines, will manufacture a skin that is optimized to reflect or absorb incoming energy. The ability to change at near instantaneous speeds allows the system to overcome the problem of suboptimal design (the trade-off

between absorbing and reflecting materials) encountered in today's stealth aircraft.

Future vulnerability reduction technologies will possibly include the use of satellite bodyguards to protect a high-value space asset. To protect the large number of high-value space assets in the future, active defensive systems must be able to respond to a wide range of threats. One way to meet this challenge is to place a large fleet of satellite bodyguards in orbits containing critical U.S. space assets. A space-based bodyguard system would consist of an integrated network of orbiting microsatellites, each performing specific subsets of the space protection mission. This would be analogous to the World War II tactic of having fighter aircraft fly escort for bombers. To accomplish their tasks, these microsatellites would be structured within a meta-system. This meta-system will be composed of individual systems working together to perform such tasks as information collection, battlespace awareness, and interfacing with other components of the cooperative distributed network.

In applying this meta-system concept to a satellite bodyguard system, individual "bodyguards" (the size of a laptop computer) will perform unique subsets of the overall mission. Some bodyguards will be tasked as sensors to identify and track possible threats, whereas others will be assigned a defensive role in which their main function will be to seek out and negate threats. These defensive bodyguards may be active or passive. Active defenders will use high specific-impulse propulsion techniques to seek and destroy a space-based threat using the high exit velocities of propellant gasses. Passive defenders will use smart materials that are capable of adapting to deflect or absorb inbound energy to minimize electromagnetic or directed energy damage to a high value asset. In a worst case scenario, the bodyguard will sacrifice itself (component shielding) to protect the high-value asset it is guarding.

The final aspect of the survivability concept is battle damage repair. After an aircraft has taken a hit, battle damage repair is required to return the aircraft to an operational status. This same concept applies to spacecraft in which battle damage repair is referred to as "reconstitution." The reconstitution of space systems is the space analogy to aircraft battle damage repair. A common example of the reconstitution concept is the replacing of heat protection tiles on the space shuttles. An example of on-orbit reconstitution was the work that space shuttle astronauts performed when they corrected the "blurry vision" of the Hubble Space Telescope. Currently, reconstitution might involve repairing degraded equipment or employing new space platforms to replace combat losses. Reconstitution of satellite constellations requires responsive space lift, availability of replacement spacecraft, and properly trained personnel to launch and operate the systems, all of which makes today's reconstitution very expensive and time consuming. The DARPA OE ACTD mentioned previously is starting to address this issue.

The nanotech spacecraft skin discussed previously also will be able to address this reconstitution issue in the more distant future. Essentially, future spacecraft will be self-healing. The nanotech skin will provide a capability for the damaged spacecraft to act autonomously to repair itself. This action will greatly reduce the demand on the space logistics system, which in space is a great advantage in time and cost.

The United States has become increasingly dependent on space assets and operations from a military and commercial aspect. Until now, little consideration has been given to the protection of these space assets. The Chinese destruction of their own satellite has clearly demonstrated their capability to kill space assets. For the United States to maintain its space superiority, the susceptibilities and vulnerabilities of our space assets must be identified and reduced. Numerous potential future susceptibility/vulnerability reduction technologies have been presented above. As with any susceptibility/vulnerability technique applied to aircraft, cost-benefit studies must be performed to determine which technology will be the most cost effective in protecting our increasingly valuable space assets. It is time to get serious about space survivability. ■

About the Author

Mathias Kolleck has 23 years of experience in survivability and vulnerability with the Aeronautical Systems Center, Wright Patterson Air Force Base, OH. He has extensive experience in fire suppression technology, having supported the Joint Department of Defense (DoD)/Federal Aviation Administration (FAA) Halon Replacement Program for Aviation and the National Institute of Standards and Technology (NIST) Next Generation Fire Suppression Technology Program (NGP). He also has served as an adjunct instructor at the Air Force Institute of Technology, where he taught the aircraft survivability course. Recent publications include the Unmanned Aircraft Systems (UAS) Vulnerability Reduction Guide (JASPO-V-04-12-001) and Survivability/Vulnerability Information Analysis Center (SURVIAC) TR-06-005. Mathias earned his B.S. in Aerospace Engineering from the University of Cincinnati. He received his MBA in Finance and M.S. in Economics from Wright State University.

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Spacecraft Survivability Engineering—Project Orion

by Meghan Buchanan and Mike Saemisch

After the Challenger disaster, the National Aeronautics and Space Administration (NASA) established the Office of Safety, Reliability, and Quality Assurance (SR&QA) to repair the "lack of independent safety oversight." Later, after the tragic Columbia accident, NASA conducted an in-depth investigation to identify causes of the accident and set forth recommendations to save the program's future. The Columbia Accident Investigation Board (CAIB) reported considerable concern over the lack of a crew escape system and an ability to address worst-case scenarios and emergencies.

"Designs for future vehicles and possible retrofits should be evaluated in this context. The sole objective must be the highest probability of a crew's safe return regardless if that is due to successful mission completions, vehicle-intact aborts, safe haven/rescues, escape systems, or some combination of these scenarios."

This article describes the application of aircraft vulnerability techniques to the next generation of manned spaced craft and the future of air and space, which Lockheed Martin believes helps close these identified gaps.

Introduction

Lockheed Martin has been studying the application of system safety to the next generation of NASA human spaceflight vehicle planned for use after retirement of the space shuttle. Through a sequence of small contracts leading up to the current Orion contract, Lockheed Martin was performing these studies and analyses to support concept development of the next generation of vehicle. A primary system design goal was the advancement of space safety through a simpler and safer design. Many studies were focused on improving crew safety by implementing such system features as abort and crew escape and seeking innovative approaches for enhancing safety. In these studies, an observation was made that an aspect had been overlooked for improving crew safety of spacecraft designs. An opportunity was identified to potentially implement new techniques with potential major increases in safety, with small or no impacts on the system design, by optimizing vehicle designs with this new consideration in mind (see Figure 1).

Spacecraft survivability, which was an element of the Lockheed Martin's winning Orion proposal, was cited by NASA as a specific strength of the proposal. This information has been presented to the international space safety communities and aircraft survivability audiences alike.

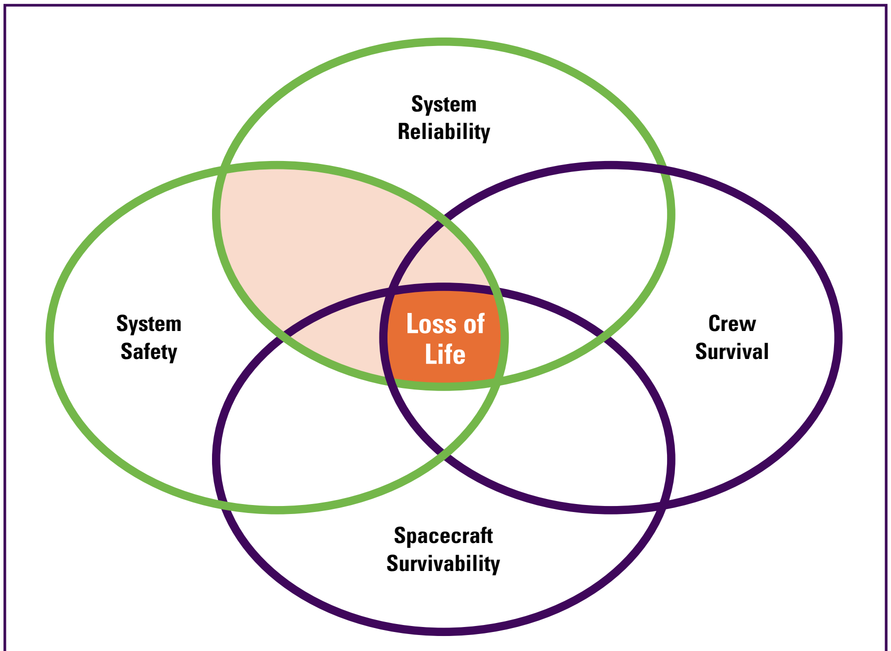

Figure 1 Prevent Loss of Life

The Need

CAIB Recommendation R4.2-4 states the following—

"Require the Space Shuttle to be operated with the same degree of safety for micrometeoroid and orbital debris (M/OD) as the degree of safety calculated for the International Space Station. Change the M/OD safety criteria from guidelines to requirements."

CAIB Recommendation R3.3-2 states the following—

"Initiate a program designed to increase the Orbiter's ability to sustain minor debris damage by measures such as improved impact-resistant Reinforced Carbon-Carbon and acreage tiles. This program should determine the actual impact resistance of current materials and the effect of likely debris strikes."

Both statements call for the "capability of a system to withstand man-made and natural threats without suffering a loss of crew or spacecraft and return safely to a safe haven or earth." Traditionally, system safety requirements are focused on eliminating hazards (not possible for most space travel hazards) or reducing the probability of occurrence to acceptable levels by preventing events or assuring essential events. If one examines typical human spaceflight safety requirement documents, the requirements provide for this hazard control through features such as designing triple inhibits to undesired events or triple redundancy for critical events (two failure tolerance). If the system provides the required features (*e.g.,* three inhibits, triple redundancy), the system is deemed as providing acceptable levels of risk, and the system can be certified for human flight. In addition, the new architecture will have provisions for removing the crew from the mishap, further assuring crew safety.

However, what if the crew does not survive the initial mishap, or what if the crew survival system itself does not survive the initial mishap risk and is not available for use? Risk is composed of two elements, *likelihood* and *severity*. By paying attention and applying requirements to only reduce the *likelihood* of occurrence of a hazard complemented with a crew survival system, the *severity* component of the initial mishap risk is not addressed through a similar structured process. Certain aspects of the potential mishap scenarios will be defined (*e.g.,* potential blast pressures) and included in the design requirements, but no structured process was being applied to examine the design for such elements as design vulnerabilities that could affect the severity of the mishap risk (consequently, the likelihood of crew survival during the mishap).

That missing link is a structured process to address severity. Severity is equivalent to vulnerability. Therefore, the definition of spacecraft vulnerability is as follows: The inability of a spacecraft to withstand (the hits by the damage-causing mechanisms created by) the naturally occurring and man-made hostile environments.

Articles from such visionaries as Dr. Robert Ball, Dr. Joel Williamsen, and Mr. Mathias Kolleck have already been published predicting the need and opportunity of aircraft survivability application to spacecraft. In 2004, a panel of NASA experts came to Lockheed Martin Aero in search of guidance from Mark Stewart and his team of vulnerability engineers.

The Application

"…many of the survivability concepts developed for aircraft apply to spacecraft as well. Given the increasing importance of space based assets, it is mandatory that designers of space systems apply these concepts to reduce the susceptibility and vulnerability of current space systems as well as insure the survivability of future systems."

—Dr. Ball and Matt Kolleck, On-Orbit Reconstruction

After the introduction to the aircraft survivability world, the initial concept of spacecraft survivability evolved for the Orion project. The concept involves the following essential elements.

Threat Identification

Aircraft vulnerability describes threats as damage-causing mechanisms created by the man-made hostile environment, whereas spacecraft survivability considers threats from damage-causing mechanisms that naturally occurring and self-induced man-made hostile environments (hazard occurrence) create. These threats range from system failures to penetration by micrometeoroids. As Figure 2 illustrates, induced threats consider such sample failures as leak, fire, process, penetration, overpressure, and operations error. Natural threats include expected events like MMOD penetration and expand to radiation, charged particles, weather, flora, and fauna. For the DMEA, these threats are narrowed to a manageable number: three to five threats.

Trade Study Support

The most significant contribution of SCS to the initial Orion design has been in support of trade studies affecting configuration. Through the assessment of survivability differences in potential options and considering these differences when scoring and making trade study selections, SCS has driven many design choices.

Design Assessment/Metric

A spacecraft survivability metric was established to measure quantitative survivability improvements resulting from design changes made during configuration changes. Each design change is scored with a derived approach. In the same manner that aircraft survivability began as a qualitative collection of opinion estimated by industry experts, the SCS metric is derived through discussions between the SR&QA and design team. SCS is the study of dealing with a "bad day scenario"—that is, failure even though fault tolerance or design for minimum risk requirements compliance has been achieved. Using SCS application, the Orion design reduces spacecraft vulnerabilities, increasing the probability of crew survivability if a mishap does occur. Eventually, actual data will be available for performing an appropriate quantitative assessment.

Damage Modes and Effects Analysis (DMEA)

Derived from military standard 1629A (MIL-STD-1629A), the overall purpose of performing DMEA is to reveal damage modes and their effects to affect design, operations, and training for decreasing spacecraft vulnerability, therefore increasing spacecraft survivability, and to document an assessment of the Orion vehicle's overall vulnerability.

Figure 2 Induced and Natural Threats

During the preliminary and detailed design phases, the purpose of the DMEA is to derive design inputs and requirements for survivability and vulnerability and to support trade studies. The DMEA provides data related to damage caused by specified threat mechanisms, identified in the process to be described, and the effects on flight and mission-essential functions. Preliminary involvement aids the development of requirements to drive a more robust design (increasing effectiveness of current design), identify areas to trade (alternate solutions), and provide inputs to emergency modes design and training or other Orion areas as they are identified.

For a spacecraft DMEA, threats are based on results from the hazard report and FMEA. The Flight and Mission Essential Functions, Missions Phases, Damage Modes, Damage Effect Levels, and Spacecraft Loss (Kill) Levels (Attrition Loss, Return Loss, Mission Abort Loss, Landing Loss and Pad Abort Loss) have been adapted to what is appropriate for spacecraft. Note also that what is formally known as "kill" levels in aircraft are referred to as "loss" levels in spacecraft. "Kill" is indicative of a wartime situation, whereas as "loss" refers to a non-violent environment yet reserves a placeholder for future definition.

To be effective in fulfilling its purpose, it is essential that the DMEA be kept current at all times with the design. The DMEA must also be consulted in the review of design changes.

Requirements Development

From the initial assessments, an important task is the derivation and implementation of new design requirements that increase crew survivability through application of SCS techniques, while living within the project constraints.

Reporting

To capture the results of the SCS efforts (DMEA and trade study scoring), existing safety data deliverables will be used to document and present this data to the air and space communities.

Future Application

The Orion SCS concept is readily adaptable to other applications in which a systematic approach to analyzing vehicles and to enhance mission success or safety is desired. It is foreseen that such analyses will become even more critical as systems are designed for longer term space travel in which safety depends even more on the robustness of the system designs. To that end, NASA has expressed a desire to immediately expand the program to include all of Constellation and possibly institutionalize SCS into the NASA processes.

Developing a spacecraft survivability program is not solely for preparing for a manned missions to Mars; rather, it is a time to bridge the gap between air and space. Large and small companies alike have dabbled in and designed space planes. This proven area of engineering has a potential to revolutionize traditional space safety practices and propel the United States far in front of the curve of future development.

Conclusion

It became readily apparent that once the concept emerged, opportunities for enhancing survivability suddenly became apparent using design features already planned or by recognizing differences of proposed options during trades studies that could drive final selection. As project engineers were exposed to the concept, the concept was embraced as a project initiative and became part of the project design lexicon. Management listed it prominently when referring to our Orion proposal.

From these early successes, we concluded that this was an initiative with true value in enhancing crew safety and one that potentially could lead to avoiding a future catastrophic human spaceflight mishap, with minimum impacts for this potentially large return on investment. It is also apparent that this program will be more valuable and essential for longer space exploration further from Earth and safety where designs should be optimized to use inherent features in the most robust system design possible.

The Orion SCS concept and initiative is only the beginning of a potentially more defined process that should be developed with Lockheed Martin, NASA, industry partners, and the aircraft survivability community to benefit all future human spaceflight vehicles and passengers. ■

About the Authors

Meghan Buchanan is the lead engineer for Lockheed Martin's innovation, spacecraft survivability, for Project Orion. In November 2003, she joined the Safety and Mission Assurance team. Earlier, she worked for Boeing, during the bidding process, as a military aircraft vulnerability engineer on the Joint Strike Fighter (F-35) and then for Lockheed Martin, after award. This experience, along with an education in Aerospace Engineering, contributed to the creation and implementation of spacecraft survivability engineering to Project Orion. In 1998, Meghan received a B.S. in Aerospace Engineering from the University of Colorado. She is currently working toward her ME in Engineering Management.

Mike Saemisch is the safety and mission assurance manager for Project Orion on the Lockheed Martin contract, responsible for safety, reliability, and quality assurance. He has more than 30 years of experience in system safety and product assurance at Martin Marietta/Lockheed Martin on National Aeronautics and Space Administration (NASA) and Air Force projects. He has worked on numerous Space Shuttle payloads, including serving as member of the Department of Defense (DoD) Space Shuttle Payload Safety Review Team. NASA projects besides Project Orion included the International Space Station, Flight Telerobotic Servicer, Crew Return Vehicle, and Space Launch Initiative. Air Force projects included DoD payload integration onto the Space Shuttle and the Titan program. Mike has established system safety processes for DoD and Lockheed Martin and participated in key system safety process and requirements documents. In 1976, Mike received a B.S. in Chemical Engineering from the University of Colorado.

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Optical Diagnostics for Ballistic Aircraft Survivability Testing

by Dr. Peter Disimile, Dr. Torger Anderson, Dr. Norman Toy, and Luke Swanson

Among diagnostics for ballistic testing at the Service survivability labs, optical methods have played an important role as tools to establish success or failure of the test or to determine the sequence of events. This has been accomplished through video imaging—acquiring a series of pictures of the test sequence to determine the times and locations of important events. However, it may be beneficial to use some of that light in a different way. The intensity of light emitted from thermal and reactive events, integrated across the image area and recorded over time during the test, has the potential to tell us much more about what is happening.

Analysis of these types of emissions is being performed in other fields, such as gas turbine engine development, to determine temperatures, pressures, gas constituents, and velocities at many locations and over time. Even though these measurements are acquired in severe conditions such as those in the engine combustor, those environments are arguably more benign than a ballistic test in an aircraft dry bay. However, some initial steps are being taken to explore the capabilities for aircraft survivability testing.

High-energy events, such as high-velocity impacts and combustion chemical reactions, release some of this energy as light across the spectrum from long-wave infrared to visible light and short-wave ultraviolet. Some of these emissions are thermal (or black body) radiation that comes from solid particles or liquid droplets in the reaction. The spectrum of this radiation can be well-characterized to determine temperature. The simplest measurement method is to break the spectrum into wavelength regions using optical filters, ratio the measured intensities, and compare the ratios to predictions. Figure 1 shows an example of such measurements acquired during the functioning of an armor piercing incendiary (API) projectile during a ballistic test. Concepts have even been developed to image the temperature distributions by acquiring simultaneous filtered images in two or more spectral regions so ratios can be generated for each image pixel. Taking it one step further by applying that to high-speed video could make it possible to monitor changing temperature distributions in a dry bay volume throughout a ballistic event.

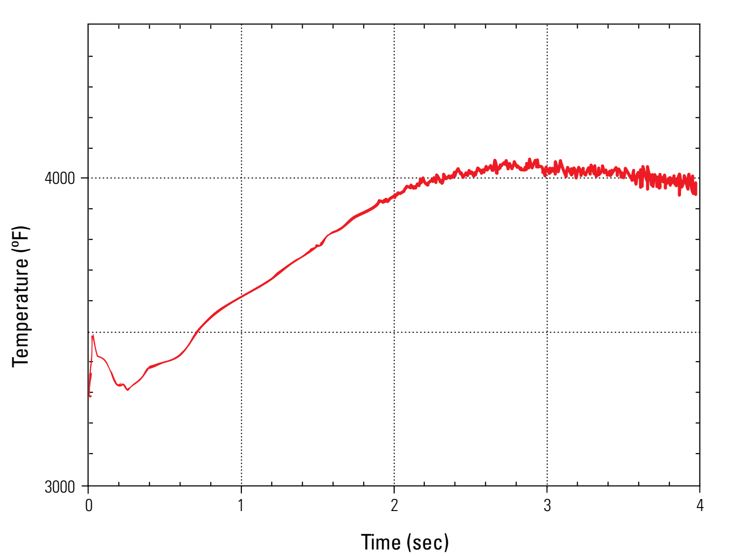

Figure 1 Temperature History From Black Body Radiation Measurements of an API Functioning During a Ballistic Test

Another approach for temperature measurements is to look at emissions from gases in the dry bay. Gas molecules at high temperatures or that were created in a chemical reaction can emit at distinct wavelengths rather than across a broadband black body spectrum. The intensity distribution creates a unique spectral shape characteristic of the constituent at a given temperature, pressure, and concentration. These spectral shapes can be predicted analytically and, by fitting the data to a library of spectral predictions, the state of the emitting gas (temperature, pressure, and concentration) can be determined without the use of a physical probe. In hydrocarbon combustion in gas turbines, for example, water vapor is a product that generates a unique and well-understood emissions spectrum that can be used to determine temperature. Figure 2 is a demonstration measurement for this technique. It may be applicable for ballistic testing, but the chemistry involved in those tests would need to be understood.

If these methods could be applied to ballistic tests, they could tell us a lot about how high-speed fragments interact with fuel to start a fire in a ballistic event. The ignition source is the flash that occurs when a projectile fragment hits a target and the kinetic energy is converted

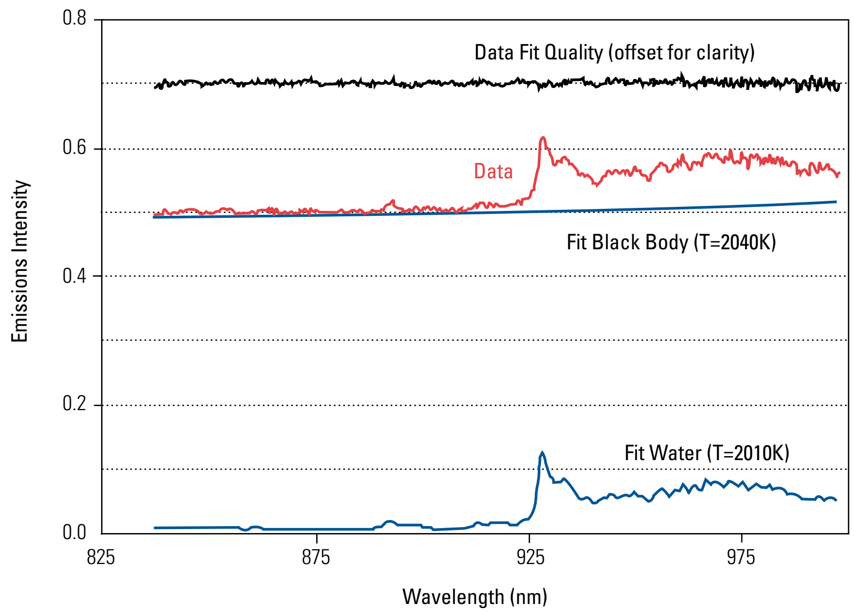

Figure 2 An Instantaneous Temperature Measurement in a Gas Turbine Combustor Based on a Combined Emissions Spectrum From Water Vapor and Soot (Black Body) (separated for temperature calculations)

to heat. If the target is a fuel tank wall, the heat energy may be sufficient to start a fire. The spectrally integrated intensity may provide an indication of whether there is sufficient energy to start a fire. The duration of the flash may be able to tell us if there is enough time for the thermal energy and leaking fuel to combine to start the fire. A better understanding of these processes could help develop ways to improve dry bay fire protection against specific threats or to develop better fire suppression strategies to interfere with the ignition processes. A lot of development is required to create a useful diagnostic. Much of what has been done, particularly in a gas turbine engine environment, is based on hydrocarbon combustion. This means pressures are usually known, eliminating one variable, and the process is nearly steady state, allowing the diagnostic to be adjusted over time for the best measurement. Ballistic tests, on the other hand, result in explosive reactions or shock waves that produce unknown pressures in very quick events and may involve incendiary or propellant reactions that hydrocarbon-based techniques will not address. It will take a lot of development to refine a technique to make the most optimal measurements under those conditions and emissions spectra because many of the incendiary reactions may not have been well characterized at this point.

However, initial steps have been taken by engineers at the Air Force's 780 TS to begin to use and develop optical diagnostic techniques. Measurements of changes in the overall flash intensity change over time during a ballistic event (incendiary or high-velocity fragment) may provide additional information. They may tell us if an incendiary projectile is acting in a "characteristic" manner for that threat, or how energy is released as a function of projectile yaw and obliquity and the target material. The intensity of broadband emissions from a fragment impact on a dry bay or fuel tank wall may be able to be correlated to the probability of generating a fire with that impact. All of this is yet to be determined, though; the first step is to begin acquiring these measurements to generate data for making these correlations.

The tests to begin this effort were carried out in Range 1 of the 780th TS, Aerospace Survivability and Safety Flight at Wright-Patterson Air Force Base, a facility utilized for ballistic and explosive testing. The fixture for these tests contained a target panel located at one end of the range, and the gun was positioned 24–30 feet from the target (see Figure 3). API projectiles or fragments fired from the gun passed through a sabot catcher (a thick metal plate with a circular hole) before arriving at the target panel (see Figure 4) and then falling into a sand pile. The targets were single panels of aluminum or composite materials.

For this investigation, a number of different types of photodetectors were chosen to observe the flash from a projectile impact, with each detector being sensitive to a spectral emission of a different wavelength range. Of the photodetectors tested, two detectors were finally chosen: a UDT and a UDT UV photodiode from OSI Optoelectronics. The photo detectors were positioned near the targets to view the front face flash, back face flash, or both. A number of optical detectors were evaluated and compared as part of these tests, and an initial trial test series was used to develop the diagnostic technique to ensure adequate signals were acquired without saturating the detectors. Some results from these tests show consistency with high-speed video imaging and provide additional insight into the energy release processes that occur in these ballistic interactions.

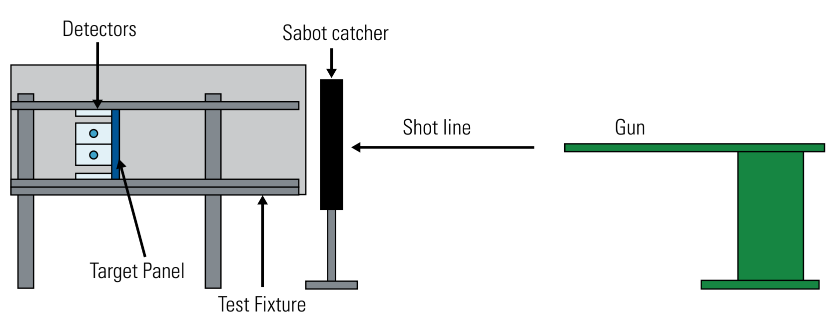

Figure 3 Experimental Setup for Testing Different Panel

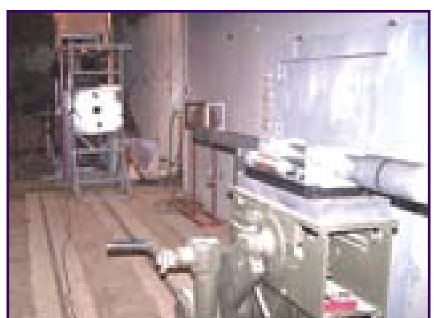

Figure 4 Gun and Test Fixture

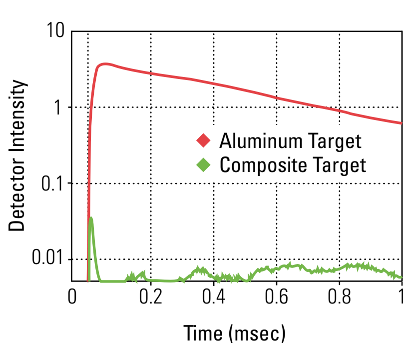

Figure 5 Relative Emissions From a High-Speed Fragment Impacting Aluminum and Composite Target Panels

Time profiles of intensity from a single detector in similar tests with two targets show significant differences associated with the target material type. In both high-speed fragment and API tests, more intense and longer flashes result from projectiles impacting an aluminum target than a target made of composite material. For high-speed fragments (see Figure 5), this may relate to how the target absorbs the kinetic energy. For APIs (see Figure 6), it is primarily the result of how the target material affects the projectile stripping and API functioning. In either case, it may be possible to determine whether the flash from the composite is adequate to even ignite a fire. With improvements in understanding the hydrodynamic ram and the fuel spray that result from the projectile impact on a fuel tank wall, it may be possible to relate the flash duration with the fuel dispersion rate to improve our predictions of fire probabilities in these types of events.

For API threats, the degree of functioning may relate to the likelihood of fire, and these measurements may help us determine that. The impact of an API on a target panel can produce at least four different types of ignition—

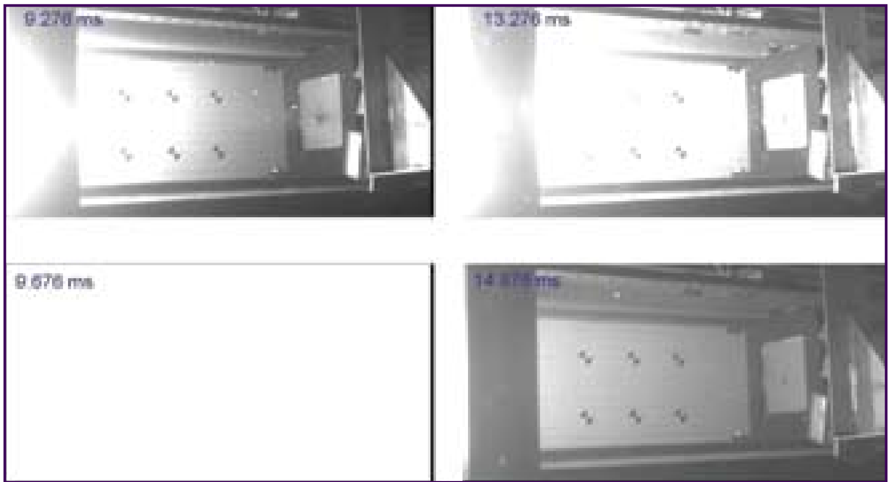

Figure 7 Delayed Function of a 12.7-mm API at 2,750 ft/s Through a 0.25-Inch Aluminum Panel

1. **Slow burn,** which occurs when the ignition begins at the target panel and forms a small, continuous column of incendiary flash
2. **Partial ignition,** wherein a small intense flash at the exit of the target panel occurs with a short flash duration and may result in a secondary flash when the API contacts another panel member
3. **Delayed ignition,** which occurs when the incendiary material ignites at a distance well beyond the target panel and has a long flash duration
4. **Complete ignition,** defined as the jacket being immediately stripped off and the incendiary mixture igniting upon impact with the target panel. It produces a large, intense flash with a relatively long duration.

Figure 7 shows an example of a delayed API function, and Figure 8 shows the emissions profiles from some of the detectors. Here the API has functioned some distance downstream of the panel (after about 9.3 milliseconds [msec]) and has produced an intense illumination (at about 9.7 msec), resulting in the saturation of the camera.

The optical sensors detected the incendiary flash and demonstrated that their capabilities complement those of the high-speed video system. Although the video sequence can follow a projectile's trajectory and give us the sequence of events, considerable analysis is required to quantify the emissions intensity variations over time. Photo detectors do this directly and with much smaller time step increments. Because the purpose of these detectors is only to acquire that data, they can be optimized for the exposure and emissions intensity to generate a good-quality signal. The need for the camera to follow low-light intensity events, such as projectile flyout and target damage, combined with the

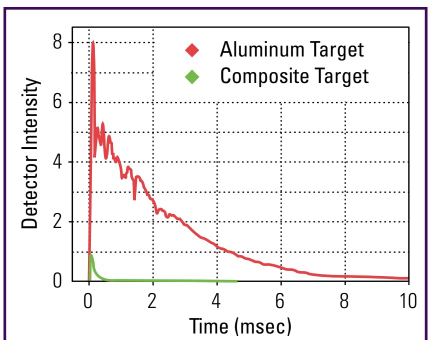

Figure 6 Relative Emissions From an API Impacting Aluminum and Composite Target Panels

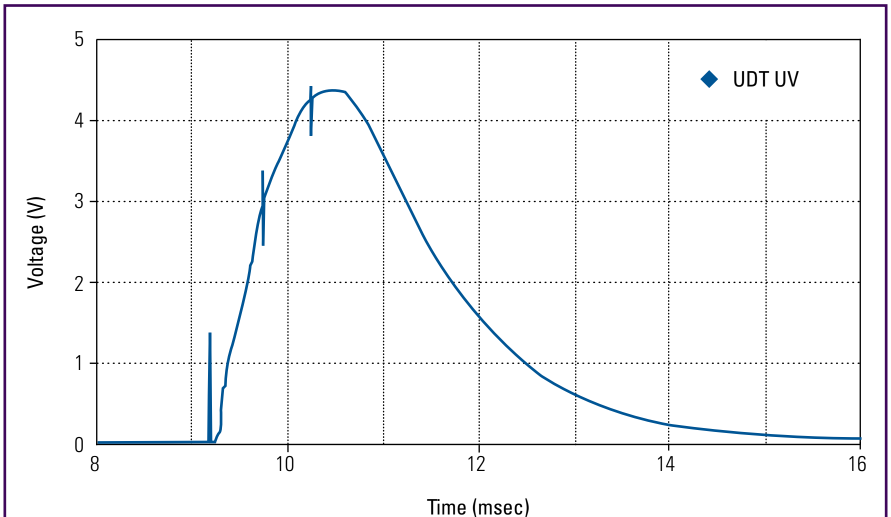

Figure 8 Response of Photo Detectors for the API Shot in Figure 7

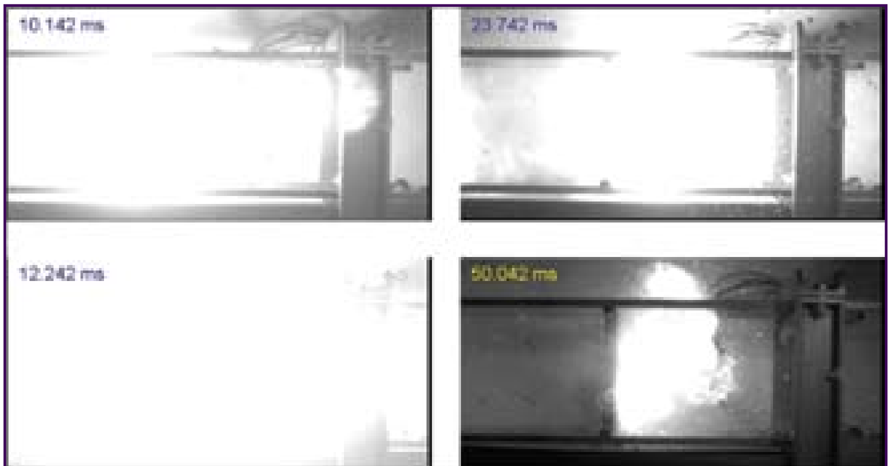

Figure 9 Fully Functioning 23-mm API at 2,000 ft/s Impacting a 0.25-Inch Aluminum Panel Set at 0°

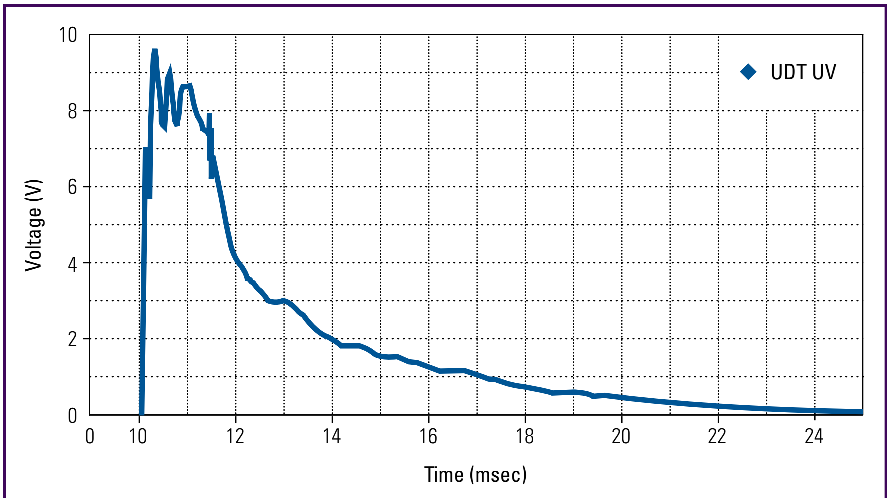

Figure 10 Full Function of a 23-mm API at 2,000 ft/s Striking a 0.25-inch Aluminum Panel Set at 0°

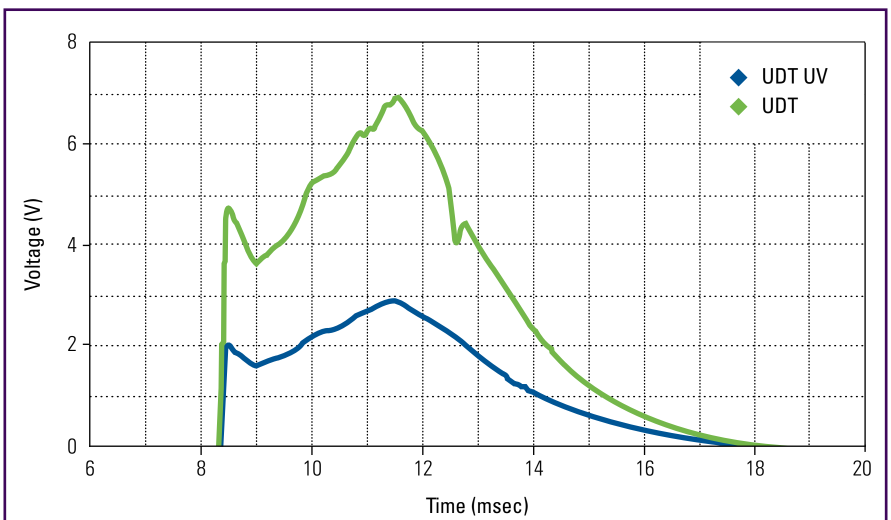

Figure 11 A 23-mm API at 2,500 ft/s Impacting a 0.35-inch Composite Panel Set at 45°

limits in intensity dynamic range, almost ensure the camera will be saturated from the flash, preventing its use in quantifying that parameter.

Finally, the addition of photodiode monitoring of these tests is a low-cost complement to high-speed imaging.

For the case where a full function occurs, such as a larger API striking an aluminum panel, the plume may be observed on both sides of the panel (see Figure 9). In this case, the plume is clearly visible at 10.1 msec, and it saturates the video camera at about 12.2 msec. It collapses on the rear of the panel at 23.7 msec but continues to burn on the front face of the panel about 50.0 msec later. The photo detector data, plotted in Figure 10, shows a more intense and longer lived emission than the delayed functioning case in Figure 8.

API impacts on composite panels may be more likely to result in partial or delayed functioning, but they may result in additional effects. Figure 11 shows the emissions following an API impact on a composite panel set at 45° to the shot line. Data from two different sensors is provided. The flash from the initial functioning shows up as a narrow peak that lasts less than 1 msec and is weaker than the other flashes shown in Figures 8 and 10. But the delayed emissions, presumably from the incendiary combined with the burning of the composite target material, provide a much longer lived emission and potential source of ignition for a fire.

These tests were just initial attempts to determine if optical diagnostics, and emissions intensity time histories in particular, can help us better understand ignition processes and the ability to control fire. The measurements show promise. Improvements in the technique are being developed to improve and characterize the field of view, reduce background lighting contributions, set the scaling to avoid sensor saturation, acquire well-resolved signals, and standardize the technique. These are easy measurements to piggyback on other tests, so a library of data can hopefully be archived in routine testing for other purposes and used to characterize the measurement capabilities and results with physical phenomena that relate to probabilities of fire. ■

About the Authors

Dr. Peter Disimile is an Associate Professor in the Department of Aerospace Engineering at the University of Cincinnati. For the past several years, he has been detailed to the U.S. Air Force 780 TS, Aircraft Survivability and Safety Flight at Wright-Patterson Air Force Base. His interest is mainly in experimental fluid dynamics and heat transfer applied to fire and explosions issues. He has

written more than 180 journal and conference publications and abstracts ranging from acoustic behavior of cavity flows to temperature measurements in a pyrotechnic event, fire ignition, and hydrodynamic ram events.

Dr. Norman Toy is the Chief Engineer at Engineering and Scientific Innovations, Inc., at its Blue Ash site in Ohio. He joined the company in January 2007 after a long career at the University of Surrey in the United Kingdom as a full-time professor in fluid mechanics. He is now a permanent resident of the United States and is involved in overseeing the programs associated with the characterization of fire hazard and suppression for aircraft survivability. He has published more than 200 journal and conference papers concerning experimental fluid mechanics.

Dr. Torg Anderson is a member of the Operational Evaluation Division at the Institute for Defense Analyses in Alexandria, VA, where he supports aircraft live fire evaluations for several programs, including the F-35, Multi-Mission Maritime Aircraft, and E-10A. He has 25 years of experience at United Technologies Research Center and Pratt & Whitney primarily developing optical and laser-based combustion diagnostics and applying them to aircraft gas turbine development. Dr. Anderson is an active member of the AIAA Weapon Systems Effectiveness Technical Committee.

Luke Swanson was a Junior Engineer with Engineering and Scientific Innovations, Inc. until January 2008. He gained his Masters in the Department of Aerospace Engineering under the auspices of Dr. Peter Disimile at the University of Cincinnati in November 2007. He has recently taken up a research position at NASA Marshal Flight Center.

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Excellence in Survivability—Gregory Czarnecki

by Dale Atkinson

The Joint Aircraft Survivability Program Office (JASPO) is pleased to recognize Mr. Greg Czarnecki for Excellence in Survivability. Greg is an aircraft survivability team leader in the Aerospace Survivability and Safety Flight, 780th Test Squadron, 46th Test Wing. Greg, a native of South Bend, Indiana, enlisted in the Navy in 1972, and served four years as an Operations Specialist. Upon completion of active duty, he joined the Naval Reserves and began undergraduate studies at the University of Dayton.

In 1978, he changed military services and enrolled in the Army National Guard. He retired after 22 years of military service. In 1980, Greg received a B.S. in Civil Engineering and began work for the United States Air Force (USAF) as an aerospace engineer within the survivability discipline. Returning to school part time, he received a masters in Materials Engineering in 1992 and has since completed course work toward a Ph.D. His Air Force career began in what is now the Air Force Research Laboratory (AFRL). Throughout his career, Greg has promoted the development, advancement, application, maturity, and credibility of modeling and testing methodologies that promote aircraft survivability.

Greg began his USAF career by applying emerging non-linear finite element (FE) methods to the solution of anti-aircraft artillery (AAA) damage effects on aircraft structures. Using a combination of modeling and testing, assessments of post-damage residual strength were conducted on F-4, A-7, and F-15 wings. At that time, the FE state of the art was in its infancy.

In the late 1980s, Greg coupled his FE and test experience with evolving structural optimization routines to perform a fly-off of composite materials under consideration for the Advanced Tactical Fighter. Equal-strength (optimally designed) test panels, representing wing skins, were fabricated from each candidate material and attached to a load fixture where they were subjected to simulated flight loads, high-speed airflow, and ballistically induced hydrodynamic ram to evaluate inherent damage resistance. The material proving to have greatest damage resistance was later adopted for application on the F-22.

Based on his interest in advanced modeling methods for assessment of hydrodynamic ram effects, Greg organized and co-hosted a Hydrodynamic Ram Workshop in the early 1990s. Top modelers and modeling houses nationwide participated. The purpose was to share test data (to establish a sense of realism) and share thoughts concerning the advantages and disadvantages of finite element analysis (FEA) based solution methods involving Lagrangian, Eulerian, combined Lagrange-Eulerian, and smooth-particle hydrodynamic approaches. Results culminated in an Air Force contractual award that Greg led that—

1. Identified well-defined and sufficiently instrumented ram tests for use as benchmarks to help mature, verify, and validate ram modeling efforts,
2. Identified the most appropriate modeling approach from competing methodologies, and
3. Verified that emerging codes were capable of achieving correlation with well-regulated tests.

Greg's FE experience proved useful when he returned to the University of Dayton to pursue an advanced engineering degree. In one class, he was assigned a special project involving a numerically unstable scenario. Only by recalling and applying a modeling "trick" was he able to solve the problem correctly and receive a top grade. He readily admits that practical experience helped pull him through the class.

More recently, Greg collaborated with General Electric and RHAMM Technologies to couple an FE model of a Man-Portable Air Defense Systems (MANPADS) missile with that of a large aircraft engine. This marked the first time that a dynamic, rotating engine model was reconfigured to credibly consider damage caused by a MANPADS impact. Although many computational hurdles had to be overcome, the effort concluded successfully with credible predictions of MANPADS damage on a non-rotating engine and extrapolations of damage to a rotating engine. Beyond pretest predictions, the effort yielded an engine-MANPADS modeling procedure that can now be applied to other engagement conditions and other engine types.

In the early 1990s, to explain complex behavioral characteristics of composite materials under dynamic conditions, Greg led an in-house impact physics research

initiative. His own research (culminating in a Master's thesis) involved the discovery and quantification of shear and stress-wave damage sequences within impacted composite laminates.

Greg continued to work with senior researchers and Ph.D. students to advance the knowledge base associated with impact physics of composites. This area remained one of the core research thrusts within his division. His contributions were in advancing instrumentation technologies, identifying impact energy absorption mechanisms, and developing an economical method of predicting the threshold velocity for penetration. Core to the method was his discovery that, for a given projectile geometry, the threshold energy for penetration is constant. In 1998, the Air Force Air Vehicles Directorate recognized the value of his contributions by awarding him with Senior Engineer/Scientist of the Year.

In the mid-1980s, Greg's attention turned toward predicting a structure's response to blast-induced hydrodynamic ram. Hydrodynamic ram is a catastrophic event caused by projectiles passing through and exploding within fluid-filled structures. When the JASPO began assessing ram phenomenology, testing was often limited to simple observations of the extent of damage sustained. Modeling was in its infancy, with some ram models computationally limited to a single element of resolution. And as though designing damage resistant metallic structure were not challenging enough, the advent of composites provided new challenges. Hydrodynamic ram sustained by composite structures under the presence of high-speed airflow was a key survivability concern. Greg designed and executed an investigation that quantified the extent of battle-damage as a function of wing skin material type, AAA projectile type, tank-fluid depth, impact location, and other parameters. Lessons learned were that composite wing skins are particularly susceptible to airflow damage when the laminate is forced farthest out of plane (*i.e.,* as ram loads or projectile blast overpressures are applied). Vast amounts of the skin material, sometimes the entire skin, are stripped away in the airstream. These and other tests generated opinions that composite structures would never be as ram tolerant as metallic counterparts; particularly regarding high-explosive (HE) threats. Some individuals held a stronger view that models would never be capable of reliably predicting the outcome of seemingly chaotic ram events.

Greg believed otherwise. As Structures Committee Chairman, he promoted and guided a series of efforts that later proved both opinions wrong. Using advanced design concepts that included toughened matrices, z-pinning, and damage-resistant joints, the Structures Committee launched a series of projects that demonstrated improvements to the ram survivability of composite structures hit by high-velocity missile fragments and large-caliber HE threats. He also designed and demonstrated the utility of airflow damage attenuation techniques for composite wing skins.

With respect to modeling the ram event and predicting structural damage, Greg championed the push to advance computational limits and assess controlling parameters of the ram solution. To support and validate ram-model developments, Greg designed and performed a series of static and dynamic experiments quantifying asymmetric ram pressure fields generated by 23-mm and 30-mm high-explosive incendiary (HEI) projectiles. He led contractual efforts to develop ram-specific modeling guidelines using state-of-the-art hydrocodes. The ram response of complex composite structure can now be predicted to a high degree of reliability as a result of these efforts.

More recently, Greg led the development of a low-cost means of assessing the inherent ram resistance of aircraft skin-spar joints. With assistance from Wright State University, RHAMM Technologies, and JASPO, a hydrodynamic ram simulator was developed and demonstrated. The new test method ensured realism while reducing test cost by two orders of magnitude. The hydrodynamic ram simulator has since been applied to assess the failure properties of joints that foreign and domestic aircraft manufacturers provide.

In the late 1990s, Greg participated in Joint Strike Fighter (JSF) Developmental Test and Evaluation designed to assess the inherent ram resistance of competing wing fuel tank designs. As a subject matter expert (SME), he helped define the tests and achieve meaningful data acquisition. Tests results proved critical to the JSF design and further supported the advancement and credibility of modeling and simulation (M&S) for prediction of ram damage. The contributions of Greg and the Structures Committee have clearly benefitted the ability of military aircraft to fly, fight, and survive.

MANPADSs are a major concern to aircraft operations within low-altitude airspace. This highly proliferated and lethal threat is mobile, hard-to-detect, and difficult-to-counter. Although early JASPO investigations concentrated on susceptibility reduction (avoiding the hit), vulnerability reduction (withstanding the hit) solutions remained undeveloped based on consensus that cost/weight would prove prohibitive. MANPADS hits and aircraft kills in Desert Storm reenergized the need for vulnerability-based solutions. Responding to a 1997 Office of the Secretary of Defense (OSD) query concerning what, if anything, could be done to limit aircraft vulnerability to the MANPADS threat, Greg joined with JASPO leadership to survey the state of the art and recommend solutions. To answer this question, he helped organize and chair the first National MANPADS Workshop. Its purpose was to—

- ➤ Reflect on Desert Storm and previous aircraft engagements with the MANPADS threat
- ➤ Assess M&S' ability to perform MANPADS vulnerability assessments and damage predictions
- ➤ Determine what, if anything, could be done to limit aircraft vulnerability to the MANPADS threat.

The workshop not only validated the magnitude of the MANPADS threat, but also demonstrated that much needed to be done to better prepare M&S to handle the threat.

In follow-on actions from the National MANPADS Workshop, Greg led the charge to assess and improve aircraft-MANPADS survivability by promoting efforts to—

- ➤ Characterize the MANPADS threat
- ➤ Solicit new and innovative MANPADS-capable vulnerability reduction solutions
- ➤ Advance modeling methodologies with respect to aircraft-MANPADS interactions
- ➤ Develop blast-tolerant rotorcraft
- ➤ Identify a developmental course of action for the JASPO concerning MANPADS issues

- Initiate a MANPADS joint test and evaluation (JT&E) project to develop near-term aircraft survivability solutions using optimal combinations of susceptibility and vulnerability reduction techniques.

Earlier, Greg developed a compendium of aircraft-MANPADS survivability activities that provided JASPO management with a quick-look means of assessing MANPADS-projects and their inter-relationships. To help potential users with MANPADS M&S venue selection, he compiled a database of the nation's MANPADS fly-out/endgame M&S capabilities. He later led an effort that assessed rotorcraft vulnerability to MANPADS as a function of hit point. Assessments performed on CH-47, AH-64, RAH-66, and V-22 systems indicated dramatic reductions in vulnerability through biasing the missile's impact toward least vulnerable areas.

Although Greg recognized the need for accurate predictions of MANPADS hit points, M&S SMEs in the National MANPADS Workshop proclaimed that credible hit-point predictions were not possible. With JASPO's assistance, Greg established a tri-service M&S team to prove otherwise. Together, they took a first look at M&S' ability to credibly make such hit-point predictions. Greg then performed a series of experiments using complex infrared (IR) target boards. To a large extent, M&S proved credible for the prediction of hit-point trends, opening the door to novel aircraft protection concepts.

One such solution was aim-point biasing, which Greg patented. Aim-point biasing is a hybrid infrared countermeasure (IRCM) concept by which the IR signature of an aircraft is altered to bias incoming missiles away from flight-critical structure to assure aircraft survival. The goal is to generate misses. By virtue of aim-point biasing, any hits that do occur would be to least-vulnerable areas. A key advantage of the low-tech system is that a missile warning system is not required because the system is always active. Although aim-point biasing remains in concept development, several advances have occurred. Under Greg's leadership, Boeing designed a prototype (lab-demo) aim-point biasing system for rotorcraft application. In a follow-on effort, Sanders Design International (under Greg's guidance) developed a derivative of the aim-point biasing concept known as spatial infrared countermeasure (SICM). Going one step beyond aim-point biasing, SICM modifies the aircraft's IR signature to assure a miss. SICM effectiveness on fixed-wing aircraft was substantiated through exhaustive M&S and demonstrated through a first round of field tests.

Leveraging off the Joint Aircraft Survivability to MANPADS (JASMAN) Joint Feasibility Study that his office performed in 2000, Greg proposed a follow-on effort in 2004. The goal was to evaluate fixed and rotary wing aircraft tactics effectiveness against MANPADS within airfield environments. The topic was accepted as a quick-reaction test (QRT) to address immediate issues that airfield commanders voiced in Iraq and Afghanistan. To execute the program, AFOTEC set up the Air Force Joint Test and Evaluation Group (AFJTEG) office and requested Greg by name to participate as an SME. Specific duties were to provide consultation concerning test construct, verify the validation of all M&S used during the QRT, provide onsite support during field test operations, and assist with data assessment and evaluation. Investigation results were provided to in-theater Iraq/Afghanistan aviation commanders to reduce the operational risks of cargo and rotary-wing aircraft.

In yet another MANPADS-related effort, Greg arranged Joint Live Fire (JLF) Program teaming with the National Aeronautical and Space Administration (NASA) to evaluate MANPADS damage effects on the horizontal tails of large aircraft. He directed a quick-look test effort that quantified MANPADS damage effects on control surfaces. NASA extended this work to assess the effects on damage magnitude and location on the aircraft's ability to maintain flight. Data produced by this JLF-NASA effort produced a first-order approximation of safety of flight for aircraft experiencing similar damage. Combined with other large-aircraft test and analysis efforts, results assist operational risk assessments and support investment decisions concerning aircraft survivability measures.

Under Greg's leadership, JASPO, JLF, NASA, and the 780th Test Squadron are also answering questions about large aircraft-engine vulnerability to MANPADS. The project plan uses a model-test-model building block approach that begins with an assessment of MANPADS damage effects on non-operational engines. The combined model-test-model effort represents a cost-effective, low-risk method of determining the likely outcome of a MANPADS incident. Early results are not only validating engine-MANPADS modeling procedures but also proving valuable to decisionmakers who are charged with operational risk assessments and with determining where and how to invest to counter the MANPADS threat. Greg's pioneering efforts and contributions have significantly improved our understanding of the MANPADS threat and will enable aircraft survivability for years to come.

As a JASPO member since 1984, Greg continues to participate in and lead technical efforts within the Vulnerability Reduction Subgroup. During 1998, he served as interim-Chairman of the subgroup and Structures and Materials Committee for the past 10 years. To date, Greg has authored or co-authored 21 published reports and 16 published papers. He consistently contributes articles to the Aircraft Survivability Journal, which we greatly appreciate.

His family consists of wife Kathy, son Aaron, and daughter Amberly.

It is with great pleasure that the JASPO honors Mr. Greg Czarnecki for his Excellence in Survivability contributions to the JASPO, survivability discipline, and warfighter. ■

About the Author

Mr. Dale Atkinson is a consultant on the aircraft combat survivability area. He retired from the Office of Secretary of Defense in 1992 after 34 years of government service and remains active in the survivability community. Mr. Atkinson played a major role in establishing survivability as a design discipline and was a charter member of the tri-service JTCG/AS which is now the JASPO. He was also one of the founders of DoD sponsored SURVIAC.

Control Surface Vulnerability to MANPADS

by Greg Czarnecki, Gautam Shah, and John Haas

The highly mobile, hard-to-detect, and difficult-to-counter Man-Portable Air Defense System (MANPADS) threat has proven capable of generating aircraft kills. The United States Forces' continued operations in the wake of Operation Iraqi Freedom (OIF) have resulted in numerous casualties from ongoing resistance in Iraq.

In addition to numerous rotary wing losses in OIF, these missile systems have hit at least three large aircraft. In each case, the aircraft type, impact point, and damage have been different. Aircraft were able to make a safe emergency landing with minimal injury to crew, passengers, and cargo. These three cases might have been a combination of good fortune and skilled airmanship or examples of the usual outcome anticipated in the future.

Need for Test and Analysis

The U.S. Transportation Command and U.S. Air Force Air Mobility Command describe MANPADS as their primary Force Protection concern. In 2003, an interagency task force (consisting of the Department of Defense [DoD], Defense Intelligence Agency, Transportation Security Agency, and industry leaders) recommended that an assessment be conducted of large aircraft vulnerability to MANPADS. A 2005 Rand report stated, "a development effort should begin immediately that focuses on understanding damage mechanisms and the likelihood of catastrophic damage to airliners from MANPADS" and "findings should inform a decision on the number of aircraft that should be equipped with countermeasures."

Except for a few MANPADS incidents in which the aircraft survived, the result of a MANPADS impact on a large multi-engine aircraft (whether military transport or commercial) is not well quantified. Large multi-engine aircraft are particularly susceptible to being hit by a MANPADS threat during takeoff and landing based on the aircraft's size, infrared (IR) signature, relatively low velocity, and lack of maneuverability. The fuel tanks of these large cargo-type aircraft are typically full during takeoff, further limiting their maneuverability and capability to rapidly climb to a safe altitude. Even those impacts that are immediately survivable might result in a loss of systems and potentially loss of life from subsequent cascading effects. Examples of cascading effects are loss of thrust, initiation of fire in the engine or wing dry bays, loss of lift, and loss of control.

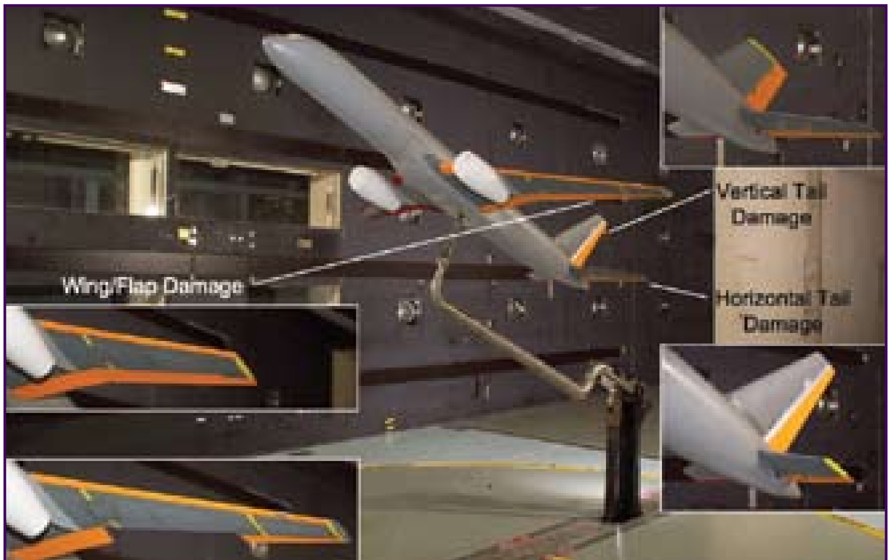
MANPADS Damage on a Large Transport Aircraft—Baghdad, 2003

To counter the MANPADS threat, the DoD and Department of Homeland Security are investing in counter-MANPADS protections methods. A layered defense is required for protecting against this threat. Protection methods for U.S. aircraft are—

1. Denial of weapons to potential threat organizations and individuals
2. Denial of opportunity to fire the weapon at an aircraft
3. Prevention of impact of the missile on the aircraft
4. Withstanding MANPADS impacts and landing the aircraft without system loss or casualties.

Investment decisions to counter the threat should be based on knowledge of the probability of hit, combined with the probability of sustaining a measure of damage affecting the mission and continued safety-of-flight.

Although MANPADS generally track toward the targeted aircraft's engines (by virtue of the engine's large IR signature), missiles sometimes impact surrounding aircraft structure, including control surfaces. Because control surfaces strongly affect safety-of-flight, the Joint Live Fire (JLF) Program teamed with NASA to evaluate MANPADS damage effects on the horizontal tails of large aircraft.



Generic Transport Aircraft Model in NASA Langley 14′x22′ Wind Tunnel

MANPADS Tests

Four tests were conducted at Eglin AFB, FL: the first two involved MANPADS shots into a C-17 composite horizontal tail, and the second two involved shots into an aluminum horizontal tail from a large commercial aircraft. Heat sources were used to attract the missile toward the intended hit point. All shots were from the aft quarter. The first shots were toward the tip of each horizontal tail to assess the (1) probability of hitting a knife-edge control surface, (2) missile's ability to detonate on the thin-skinned structure, and (3) extent of damage sustained. Once damage was quantified, a second round of shots was directed toward the mid-span with the control surface rotated 30 degrees down. The objectives were the same as above. Misses and miss-distances, warhead functioning, and the extent of damage were recorded.

Two distinct cases of damage were noted: (1) when the missile failed to detonate, the missile simply punched its way through the structure, and damage remained local to the shotline, and (2) when the missile detonated, damage proved significant and was a function of the design and material of the aircraft structure.

Assessment of Safety-of-Flight

The National Aeronautics and Space Administration (NASA), Langley Research Center, used data resulting from the JLF test effort to determine safety-of-flight implications for aircraft experiencing similar damages. NASA based its assessment on wind tunnel tests of a transport aircraft configuration. NASA researchers applied varying degrees of incremental damage (including levels analogous to that sustained during JLF tests) to horizontal tail, vertical tail, and wing elements of the wind tunnel model to measure the resulting effects on aerodynamic stability and control characteristics. The analysis was conducted based on the assumption that MANPADS damage to the vertical tail and wing would be similar to that sustained by the horizontal tail. Although this assumption might be arguable (particularly for the wing), without further testing the assumption represents a good first approximation. NASA's analysis was limited to aerodynamic effects; it did not consider issues associated with structural integrity or the potential effect of damaged internal subsystems, both of which NASA identified as being necessary for a complete survivability assessment.

Summary

Several aerodynamic factors can affect aircraft stability and controllability in the presence of MANPADS damage, among them: damage location and size relative to aircraft size, availability of multiple or redundant control surfaces both within and outside of the affected control axis (be it pitch, roll, or yaw), and location of the aircraft's center-of-gravity. Data from the JLF-NASA effort were used to produce a first order approximation of safety-of-flight for aircraft experiencing similar damages. When combined with other large-aircraft test and analysis efforts, results will assist operational risk assessments and support investment decisions concerning aircraft survivability measures. ■

About the Authors

Greg Czarnecki is an aircraft survivability team leader in the Aerospace Survivability and Safety Flight, 780th Test Squadron, 46th Test Wing. Please see "Excellence in Survivability" on page 18 for more information.

Gautam Shah is a Senior Research Engineer at NASA Langley Research Center, Hampton, VA. He has been investigating flight dynamics issues for military and civil aircraft for over 20 years. As a member of the NASA Aviation Safety Program team, he is the lead for the modeling of aerodynamic stability and control characteristics for transport aircraft under damage or failure conditions. Gautam received a B.S. in Aeronautical Engineering from Embry-Riddle Aeronautical University, and M.S. in Mechanical Engineering from The George Washington University.

John Haas is the Principal Engineer for Skyward, Ltd. based in Dayton, OH. He has a Bachelors of Science degree in Engineering Physics from Ohio State University and a Masters of Business Administration degree from Wright State University. Mr. Haas's career in aircraft survivability/vulnerability testing and analysis has spanned over fifteen years. It has included ballistic live fire test and evaluation of many Air Force aircraft, as well as numerous vulnerability reduction concept evaluation programs.

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Satellite Vulnerability to Direct Ascent KE ASAT:
Applying Lessons Learned from NASA, Missile Defense, and Aircraft Survivability Programs

by Dr. Joel Williamsen

On January 17, 2007, China launched a direct ascent kinetic energy anti-satellite (KE ASAT) missile to intentionally impact and destroy a retired Chinese-operated Fengyun-1C polar-orbiting weather satellite operating at 800 kilometers. The U.S. Space Surveillance Network has since cataloged more than 2,200 trackable debris fragments larger than 10 centimeters originating from this collision. This single event elevated the trackable orbital debris population in low earth orbits (LEO) up to 2,000 kilometers by about 10 percent and doubled the trackable objects at altitudes of 800 kilometers, where many satellites (including the U.S. Iridium system) reside (see Figure 1). Worse, the National Aeronautics and Space Administration (NASA) estimates that this single impact generated more than 35,000 particles of debris larger than 1 centimeter. Orbital debris in LEO have a velocity relative to other satellites, ranging from 2 to 15 kilometers per second (with an average velocity of 9 kilometers per second); consequently, many of these particles could easily cripple a satellite.*

This successful test not only demonstrated China's new capability to destroy a targeted satellite in LEO with a surface-based missile (as a primary threat) but also raises the specter of a potential (and perhaps intentional) secondary threat with broad consequences—a generation of orbital debris as a threat to general satellite survivability. This secondary threat of widespread orbital debris, although undirected, would be far more likely to disadvantage a nation such as the United States, with its far heavier dependence on a satellite-based infrastructure, than a nation such as China and could be an effective strategy for "leveling the playing field" in future conflicts.

With the U.S. military and economic infrastructure critically dependent on LEO satellites for command, control, and communication, it is imperative that the United States begin immediately to improve its assessment and level of satellite survivability, considering the primary and secondary nature of the

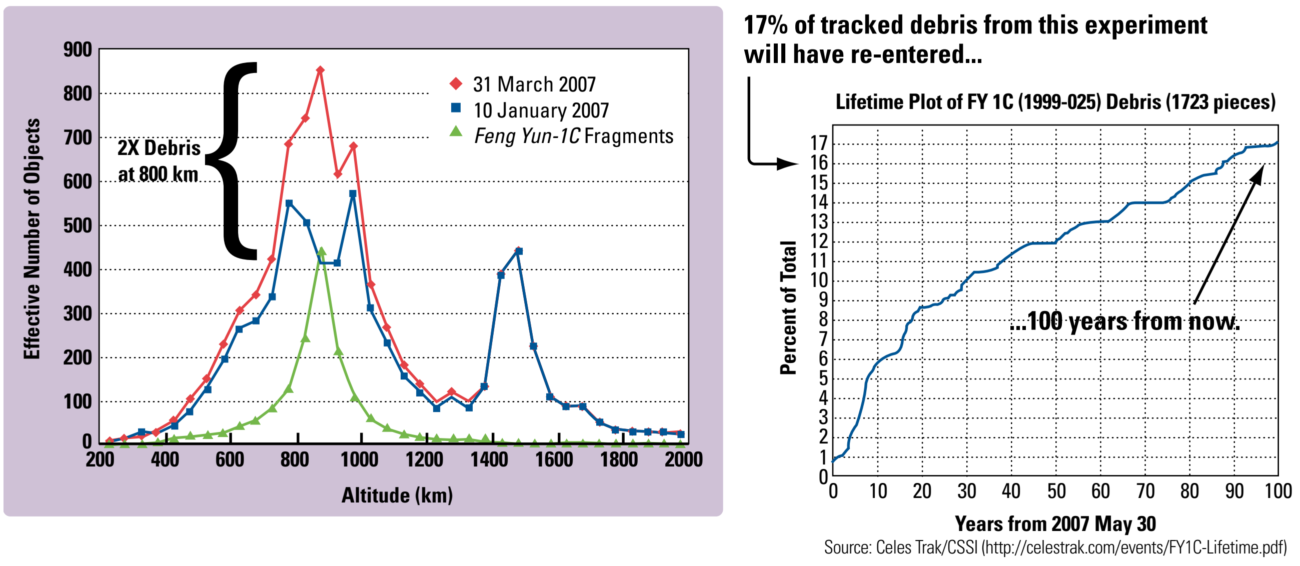

Figure 1 Effect of Chinese ASAT Experiment on Orbital Debris

*The kinetic energy of mass moving at 10 kilometers per second has roughly the same explosive energy as 10 times that mass—that is, a piece of debris weighing 10 grams and traveling at that speed would have roughly the same explosive energy as 100 grams of TNT

KE ASAT threat. Examining spacecraft survivability in greater detail would enable the military to—

- ➤ Better determine its expected degradation in spacecraft performance and mission effectiveness
- ➤ Better define its spacecraft reconstitution needs
- ➤ Provide operational or redesign options to avoid "cheap" kills, including separation and redundancies, collision avoidance and orbital maneuvering, and/or shielding in limited areas.

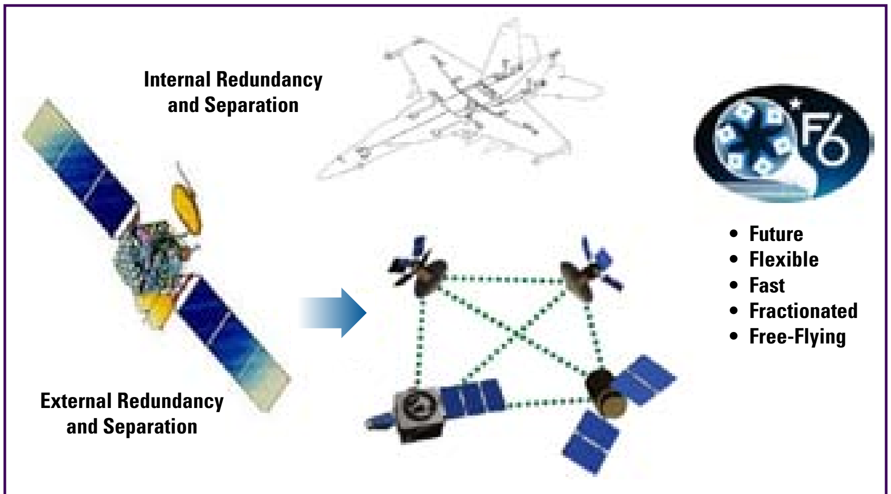

Figure 3 Critical, Redundant Subsystems Can Be Separated Internally (F-18 Aircraft) or Externally (DARPA's Proposed Wireless "SmallSats" Replacing Single Spacecraft)

Existing JASP Models Could Help Address the Issue

If the U.S. military were to decide to assess and reduce its satellite vulnerability from KE ASAT threats, it could count on "bootstrapping" its initial efforts by using important resources that have already been developed through other government entities, including the Missile Defense Agency (MDA), NASA, and the Joint Aircraft Survivability Program (JASP) (see Figure 2). The MDA tools, for example, were designed to examine the impact of missile bodies (similar to the KE ASAT) on incoming warheads and missile bodies; however, they do not examine the secondary effects of the orbital debris generated by such impacts.

NASA's spacecraft survivability analysis tools were developed to examine the proliferation of orbital debris from on-orbit impacts and the probability of penetrating other satellites by "secondary" orbital debris. The most commonly used NASA tools are limited, however, because they assume that all debris are spherical and do not include the damage effects (not necessarily disastrous) of a penetration on the interior of a spacecraft (*i.e.*, they often equate penetration to a "kill"). These specific shortcomings often cause NASA tools to overpredict penetration risk in satellites and thus overpredict failure rates and needed replacement rates for satellites.

JASP aircraft vulnerability evaluation models (*e.g.*, COVART) contain features that address these shortcomings, including the moderating effects of internal hardware shielding, redundancy, and separation on reducing risk of vehicle loss from individual penetrations. They also contain a fast-running DoD penetration prediction model, FATEPEN, which considers fragment shape and orientation in calculating the likelihood of penetration. A recent study, using a combination of FATEPEN and hydrocodes, indicates that orbital debris penetration risk to satellites might be currently overpredicted by a factor of two to four by continuing to assume that all debris of a given "size" (based on its radar cross-section return) are spherical. This assumption is based on NASA's own models for debris propagation, based on ground-based impact tests of satellites (SOCIT), indicate that impact debris fragments typically are "flake" shaped, and these shapes are much less massive (and less penetrating) than spheres of equivalent radar cross-section.

Another potentially key contribution to enhance satellite survivability would be to establish a tri-service organization for satellites similar to JASP, dedicated to survivability. An entity such as JASP,

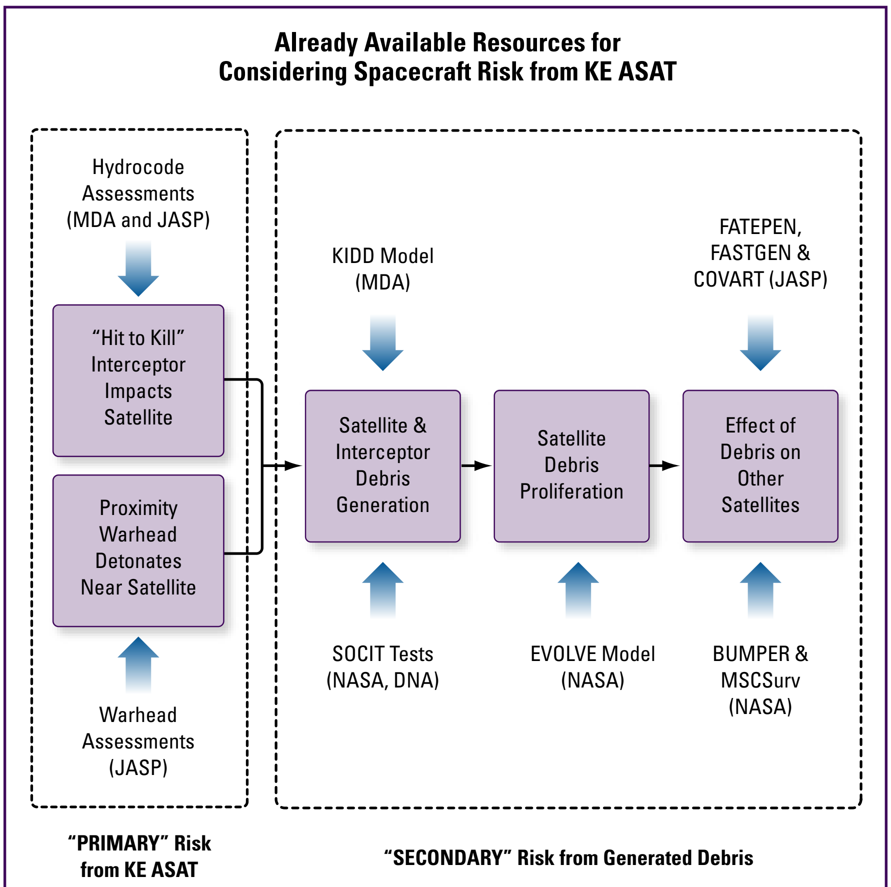

Figure 2 Existing Analytical Resources Applicable for KE ASAT Risk to U.S. Satellites

Table 1 Lessons Learned That Apply to Spacecraft Survivability from KE ASAT

1. Consider the entire "kill chain." Survivability improves through reducing susceptibility (probability of hit) and/or vulnerability (probability of kill given a hit). • The "primary" KE ASAT threat (from the missile itself) can be stopped at many points along the kill chain by employing susceptibility or vulnerability reduction. • However, some vulnerability reduction is needed for the "secondary" threat of orbital debris generated by the primary impact because (similar to small arms fire against aircraft) it usually cannot be tracked.
2. Consider threat directionality to optimize shielding allocation. Debris approaches primarily from the "front" and "sides" of a spacecraft, not from its "top," "bottom," or "rear" (compared with its velocity vector).
3. Most particles of debris created by on-orbit collisions in LEO are small and reenter within a few days; therefore, establish a safe mode for these high-threat periods, including a preferred flight orientation that shields or reduces the exposed area of the satellite's vital components.
4. Use redundancy and separation of systems to reduce overall vulnerability. This action could be applied to internal subsystems or to breaking the satellite into separate flying platforms with wireless connections, such as the F6 concept under development by Defense Advanced Research Projects Agency (DARPA) (see Figure 3).
5. Strive for dual use of structures and advanced materials. Spacecraft external radiators make good shields.
6. Consider impact obliquity and shape for reducing perceived risk. Assuming spherical debris particles and normal impact add unnecessary conservatism in risk assessment, and ultimately, weight to the satellite. A detailed risk assessment software saves weight and reduces perceived risk.
7. A joint survivability organization (such as JASP) creates a pool of available technology, reduces survivability costs, and assures "buy-in" from all services.

with its capability to fund joint technological and analytical tools for enhancing survivability of satellites and to distribute them to government and contractor entities through its close relationship with the Survivability Information and Analysis Center (SURVIAC), would give all services a vital tool for establishing and meeting meaningful survivability requirements. However, the chief impediment to implementing this sort of solution is the conservative classification (some would say over-classification) of satellite design details. For an organization like JASP to operate, satellite survivability-enhancing technology must be shared at no more than the Confidential or Secret (Collateral) levels; however, satellite design and operating details are often at Top Secret, sensitive compartmented information (SCI) levels. Survivability-enhancing analytical tools or technologies (*e.g.,* shielding, situational awareness, and redundancy/separation) need not match these high classification levels before being distributed, but an agreed-on, common spacecraft platform at a lower classification level should be established before verification and validation of the tools occurs.

Other Lessons Learned From NASA, MDA, and JASP

Table 1 summarizes other "lessons learned" that are familiar to many aircraft survivability engineers but are mostly unfamiliar to satellite designers, who for years have operated from a "safe zone" mentality. China's recent development and demonstrated *use* of the KE ASAT demonstrates that this mindset is incorrect and must be corrected before the United States faces its own "Pearl Harbor" in space. ■

About the Author

Dr. Joel Williamsen is the task leader for fixed wing aircraft live fire test and evaluation within the Operational Evaluation Division at the Institute for Defense Analyses in Alexandria, VA. Joel supports fixed wing aircraft live fire evaluations for acquisition programs, as well as Joint Live Fire assessments for existing fixed wing aircraft and rotorcraft in support of the Director, Operational Test and Evaluation of the Department of Defense. Dr. Williamsen has received the Army's Research and Development Achievement Award for armor/anti-armor design, and NASA's Exceptional Achievement Medal for "advancement in the state-of-the-art of orbiting spacecraft hypervelocity impact and survivability analyses." He is an Associate Fellow of the AIAA, and a former chairman and an active member of the AIAA Survivability Technical Committee.

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Effectiveness of Solid Propellant Gas Generators in Engine Nacelle Simulator

by John Kemp and Dr. Peter Disimile

In the early 1990s, a ban of Halon chemicals went into effect. This environmentally friendly movement motivated the Services to find an alternative yet effective means of extinguishing a fire in an aircraft. By the mid 1990s, a program titled "National Halon Replacement Program for Aviation" searched for a chemical replacement for Halon 1301. Additional programs sought to replace Halon bottles with non-liquid fire extinguishing systems, such as solid propellant gas generators (SPGG). During a previous fire extinguishing investigation conducted in the winter of 2005, a United States Air Force (USAF) team at Wright-Patterson Air Force Base (WPAFB) created a replica of the Apache T-701 engine nacelle, which was more cost-effective than full-up testing. Its purpose was to examine the effectiveness of other fire extinguishing agents on fires started in the replica. Figures 1 and 2 show a SolidWorks model and the steel construction of the Apache engine nacelle simulator.

The same high-fidelity article was used in the current test program at the 780th Test Squadron Aerospace Survivability and Safety Flight (780 TS/OL-AC) Aircraft Engine Nacelle (AEN) test facility.

Experimental Setup

The present study examined the effectiveness of active SPGGs in extinguishing strategically located fires in the engine nacelle simulator. The term "active" refers to the presence of a chemical imbedded in the solid propellant of the gas generator; in the current case, the chemical was the chemically active agent potassium carbonate, K_2CO_3. The study was conducted in two phases. Phase I concentrated on defining the airflow moving in and around the apache engine simulator. Defining the airflow in the simulator allowed the team to draw stronger conclusions and explain inconsistencies concerning the effectiveness of the SPGGs. Two data-gathering techniques were used in Phase I for louver doors both open and closed. Particle illumination velocimetry (PIV) provided a two-dimensional vector flow field in the engine nacelle environment. Constant temperature anemometry (CTA) measured the velocity at various locations along the engine nacelle simulator. The PIV technique used a smoke generator, green light-emitting diode (LED) strips (see Figure 3), and a high-speed digital imaging system.

Usually, PIV is accomplished with a laser to provide the illumination. After experimenting with green LED strips, the study determined that these were a suitable, cost-effective replacement. The high-speed cameras acquired data at 250 Hz through a set of four windows built into the test article. The smoke was put into the flow field, the LEDs illuminated the smoke, and the camera took the appropriate high-speed digital pictures. A total of 2,000 frames of data were acquired per condition. Pairs of high-speed digital images were analyzed using a commercially available

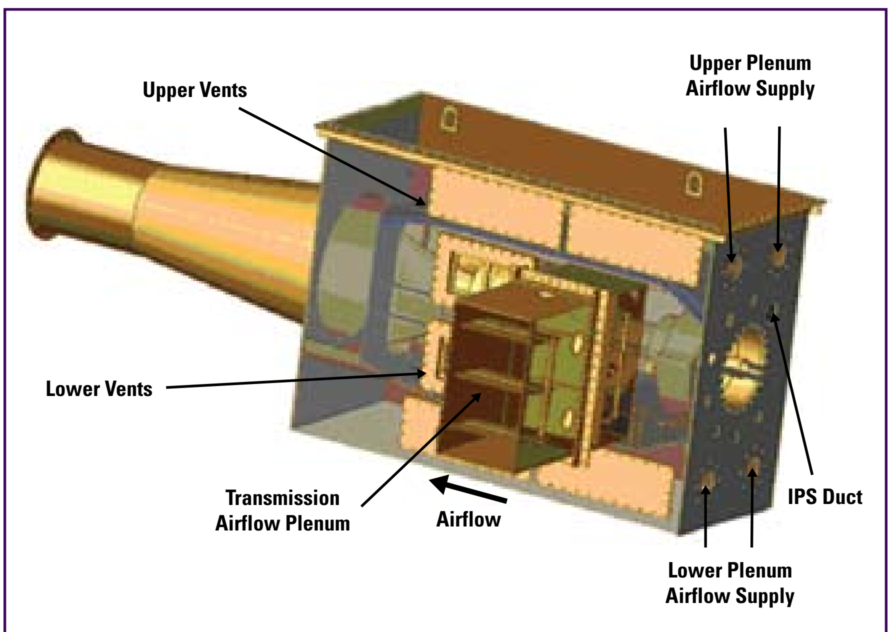

Figure 1 SolidWorks of Engine Nacelle

Figure 2 Steel Construction Simulator

Figure 3 Green LED Strips for Smoke Illumination

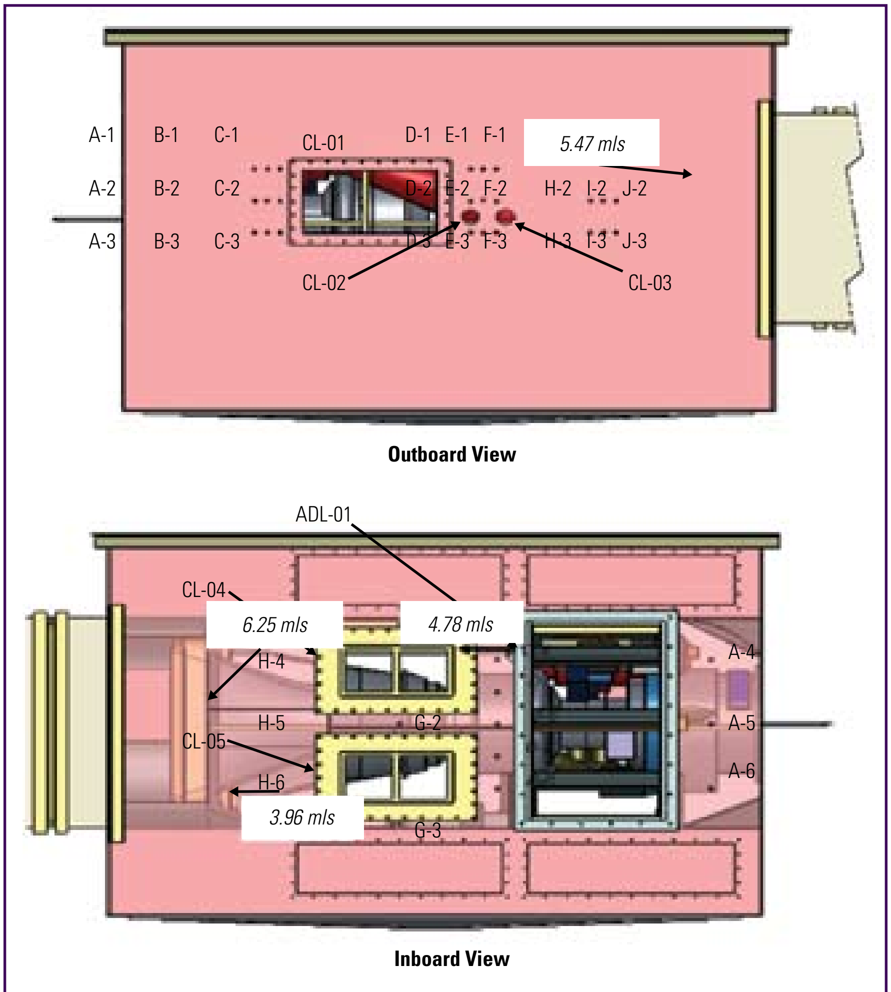

Figure 5 Outboard and Inboard Views With CTA Velocities

software package. Ultimately, the vector field was averaged into the resultant flow field for the particular louver door condition. Figure 4 shows the output of the software, which was a set of resultant flow fields for the louver doors open condition. Each square represented the flow field in a particular window. The larger arrow in the figure indicates a faster flow. A dot indicates an average velocity of 0 feet/second. The heat shield sits on top of the engine nacelle components and is present in the figure for reference.

The CTA procedure used Dantech research grade anemometry probes placed in the flow field at strategic locations. Figure 5 shows a typical result from the CTA data gathering; note the velocity vectors in the figure.

The flow field moved from right to left in the inboard view (bottom of figure), while the outboard flow moved from left to right (top of figure). Figure 5 also shows the built-in windows in yellow on the inboard view.

Phase I Results

The combined results of Phase I are as follows. When above the heat shield in the engine nacelle simulator, the flow travels upward. Below the heat shield, the flow travels to the bottom of the simulator. A vertical flow field exists upstream when louver doors are closed. Also, the same vertical flow field exists farther downstream when louver doors are open. Based on the resulting vector fields, it was possible for the center of the nacelle wall to not receive adequate fire suppression agent. The presence of a transmission flow keeps the strong horizontal component in the flow field. With louver doors open, horizontal downstream flow is about 5 m/s at agent location. With louver doors closed, little or no flow exists at the agent dispersal location.

Phase II Setup

The second phase fired the SPGG units at predetermined locations in the engine nacelle simulator. The SPGG units were acquired from the vendor Aero Jet, Inc., located in Redmond, WA. These particular units were selected because they are considered commercial off-the-shelf (COTS) products. Each unit contained 150 grams of solid propellant. Three units were used in the engine nacelle simulator per test. This produced 450 grams of propellant to extinguish a fire. As directed by the vendor, two of the 150-gram units were fired simultaneously, while the third unit fired 100 microseconds (ms) after the initial two. This timing arrangement simulated one 450-gram unit with three-150 gram units. The SPGG unit has a number of ports to discharge the propellant. The units have four columns of ports or holes 120 degrees from each other. The static SPGG unit is shown in Figure 6. The ports were covered until the SPGG unit ignited. Figure 7 illustrates a discharging SPGG unit.

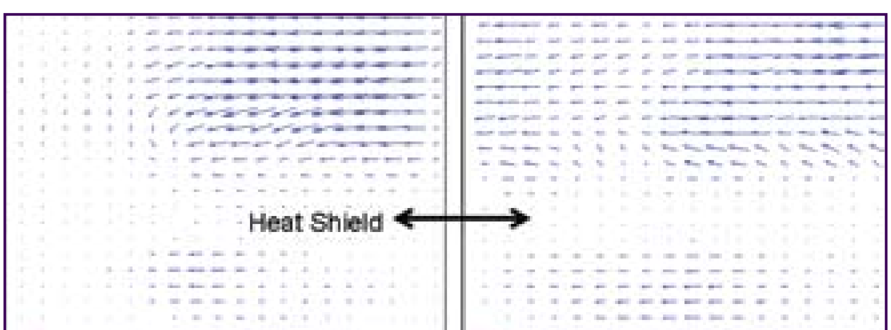

Figure 4 Vector Flow Field for the Louver Doors Open Condition

Figure 6 Static SPGG Unit

The byproducts from the ignition of the SPGG were carbon dioxide, nitrogen, water, and K_2CO_3. Two thermocouple rings were installed at nearly opposite ends of the engine nacelle simulator, which captured fire propagation and agent distribution in the simulator. Ring A had 14 thermocouples spaced around the test article approximately 17 inches downstream of the fire zone. Ring B had 22 thermocouples and was about 35 inches downstream of the fire location. There were three fire locations chosen at different locations around the nacelle. If the test results were acceptable, then the same fire locations would be checked with two SPGG units or 300 grams of propellant to determine the effectiveness of the lesser amount. The primary fuel flow rate in the engine nacelle simulator is 2 gallons/hour. The secondary fuel flow rate in the engine nacelle simulator is 6 gallons/hour. Variations were accomplished during testing using the secondary fuel flow rate. Once testing started, the louver doors were closed on the engine nacelle simulator 17 seconds after the fire was ignited. Ignition of the SPGG unit occurred 3 seconds later. Louver doors in a closed configuration during an engine fire was an operational detail communicated to us and confirmed by several Apache pilots.

Phase II Results

A total of 34 fire tests were conducted. Again, three fire locations were tested with three units per location. Remember that it took five repetitions of three SPGGs each to determine that the units successfully extinguished a fire at a particular location. Three units successfully extinguished fires under the primary fuel flow rate at the three fire locations. Because of the number of units available, fewer repetitions were necessary at the secondary fuel flow rate. Two of the fire locations saw extinguished fires at the higher, secondary fuel flow rate. At the fire locations tested, two SPGG units did successfully extinguish the fires.

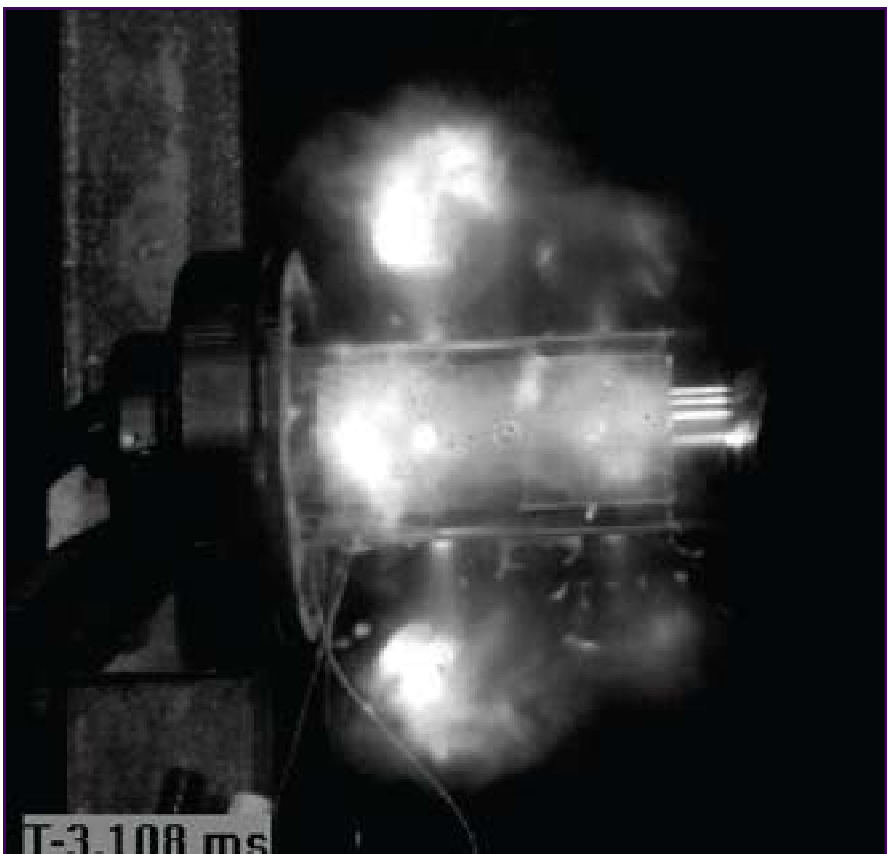

Figure 7 Discharging SPGG Unit

However, the consensus was they would not prevent re-lights from misting fuel in most of the cases.

Figure 8 illustrates a plot of typical, solitary thermocouple results.

The thermocouple in the fire shows that the temperature rapidly decreases when the SPGG is discharged. The plot shows the response time to extinguish a fire is approximately 75 ms. Figure 8 also shows that the temperature of the discharging unit is much lower than that of burning JP-8. Figure 9 shows contour plots of temperature versus an x and y location for thermocouple ring B. The black circle represents the geometry of the engine nacelle with the temperature gradient surrounding.

The green zones show the locations where the gas generator discharge is more abundant, thus causing the cooler temperatures. The orange contours show where the discharge is low in quantity, thus causing the higher temperatures. The blue in the upper-right corner is a result of the geometry of the engine nacelle simulator.

Conclusions

Given the types of fuel flows and fire locations, three SPGG units, or 450 grams of propellant, successfully extinguished all fires in the various scenarios. Engine clutter plays a large role in fire extinguishing effectiveness because agent is not evenly distributed around the engine nacelle. This may cause problems with highly cluttered regions in conjunction with extinguishing fires. Because the test simulated a 450-gram unit with three 150-gram units, the gas discharge distribution will have somewhat different behavior when comparing the three versus one larger unit. As with other SPGG units, an overpressure was detected to be several hundred psi, with a duration of 1 ms. The pulse was only measured near the discharge location and was not detected on the opposite side of the nacelle. The implication is that the pulse is a localized event in the simulator. Critical components could be moved away from the SPGG unit to avoid the pulse.

Testing showed three units provide an adequate level of fire protection, and two units do not. The data indicates SPGG units are an effective, suitable method of fire protection for the AH-64 engine nacelle environment. They have the

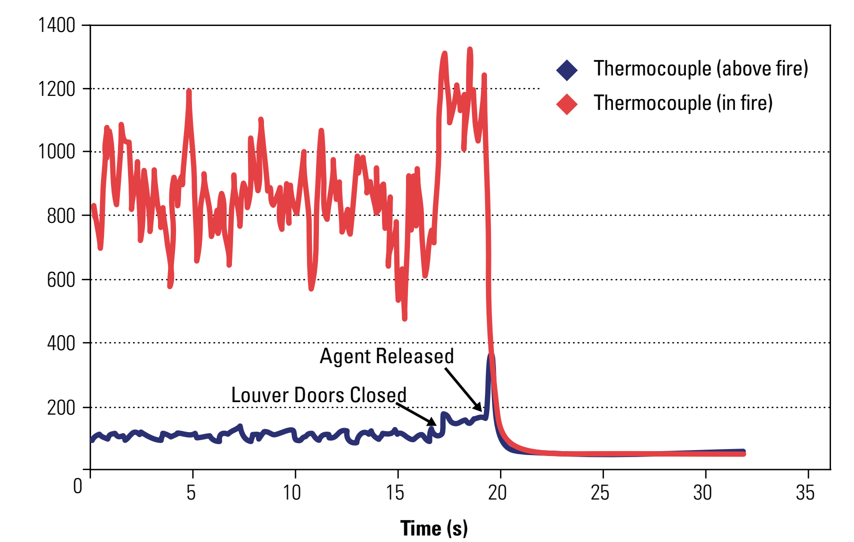

Figure 8 Typical Thermocouple Results

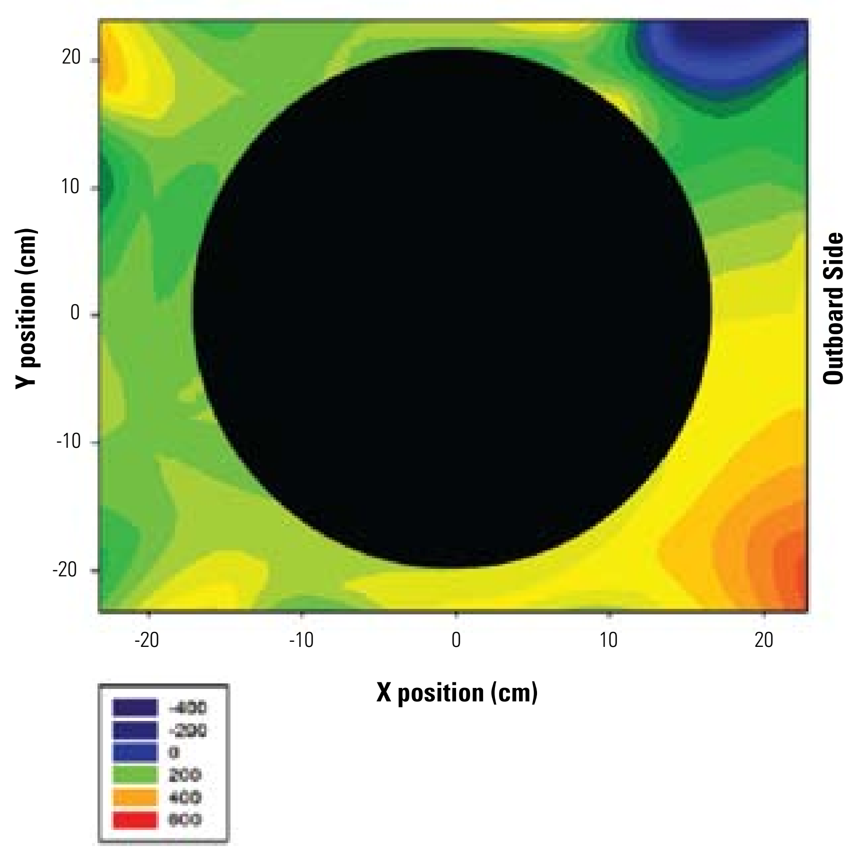

Figure 9 Typical Thermocouple Data From Ring B

potential to provide a lightweight and effective alternative to other fire extinguishing systems. ■

About the Authors

John S. Kemp is a Senior Program Engineer for the 780th Test Squadron at WPAFB, OH. He has been with the USAF and 780th Test Squadron for 5 years. Previously, John spent 5 years as a design engineer working in new product development in an aerospace and manufacturing industry environment. He also spent 4.5 years as an engineering contractor with the USAF. He has been a lecturer at v Community College for the past 10 years. John has an M.S. in mechanical engineering from the University of Dayton and a B.S. in aerospace engineering from the California State Polytechnic University, Pomona. He is now responsible for project and resource management; test and project planning; and survivability, ballistic, and fire testing at WPAFB.

Dr. Peter J. Disimile is an Associate Professor in the Department of Aerospace Engineering at the University of Cincinnati. Previously, he was detailed to the 780th Test Squadron, Aircraft Survivability and Safety Flight at WPAFB, OH. His interest is mainly in experimental fluid dynamics and heat transfer applied to fire and explosion issues. He has written more than 180 journal and conference publications and abstracts ranging from acoustic behavior of cavity flows to temperature measurements in a pyrotechnic event, fire ignition, and hydrodynamic ram events.

References

1. Bennett, M.J., Caggianelli, G.M., Kolleck, M.L., and Wheeler, J.A., "Halon Replacement Program For Aviation, Aircraft Engine Nacelle Application Phase II—Operational Comparison of Selected Extinguishants," WL-TR-97-3076, WPAFB, OH, May 1997.

Paul Deitz Named 2008 Hollis Award Winner

by Eric Edwards

On February 26, 2008, the Test and Evaluation (T&E) Division of the National Defense Industrial Association (NDIA) honored Dr. Paul Deitz as its ninth annual recipient of the Walter W. Hollis Award for lifetime achievement in defense T&E. NDIA presented the award to Dr. Deitz at its 24th National T&E Conference, held in Palm Springs, CA.

Deitz addresses T&E professionals after receiving the 2008 Hollis Award (photo courtesy of Marco Ciavolino).

During the ceremony, Mr. Jim O'Bryon (last year's recipient) presented a synopsis of Dr. Deitz's four-decade career and read the award citation. Then, the 81-year-old Walt Hollis himself stood and briefly addressed the crowd.

"Not only is all of that true," Hollis said, "but on top of that, he's a great human being." The former Deputy Under Secretary for the Army also addressed Dr. Deitz personally. "Paul, you have done well, and we want you to continue to do even better."

In response, Dr. Deitz, who now serves as Acting Director of the Human Research and Engineering Directorate (HRED) of the U.S. Army Research Laboratory (ARL), noted how pleased he was to receive this award.

"Even being a tiny footnote associated with Mr. Hollis's career," he said, "is a great thing." Dr. Deitz also noted how surprised he was to be selected because much of his career has involved activities outside of the T&E arena. "But I am certainly privileged to be an adopted member of this community," he said.

Dr. Deitz began his career in 1964 as a physicist at the U.S. Army Ballistic Research Laboratory (now ARL) at Aberdeen Proving Ground, MD. His early work was dedicated to laser scintillation testing, eye-damage modeling studies, and smart weapon evaluation. He also led efforts in ballistic live-fire simulation, testing, and analysis, significantly improving the vulnerability/lethality (V/L) of numerous major combat systems.

In the early 1980s, Dr. Deitz was responsible for the first BRL-CAD project, a 3-D CAD visualization of a combat system (an XM-1 tank). This breakthrough technology gave V/L practitioners, for the first time, an ability to view and analyze combat systems on a computer screen. Dr. Deitz also became known as the father of the widely used MUVES and SQuASH vulnerability analysis tools. In addition, he was the primary developer of the Missions and Means Framework (MMF), a conceptual structure for linking warfighter objectives to materiel performance.

Hollis presents the award bearing his name (photo courtesy of Marco Ciavolino).

Before assuming his current position at HRED, Dr. Deitz served as Technical Director of the U.S. Army Materiel Systems Analysis Activity, as Acting Director of ARL's Survivability/Lethality Analysis Directorate (SLAD), and as a Branch and Division Chief in SLAD's Ballistic Vulnerability/Lethality Division. He also is an advisor to the Army Science Board and has authored more than 60 technical publications addressing wave propagation, laser eye damage, smart munitions, geometric modeling, predictive signatures, ballistic simulation, and military effectiveness. Recently, he co-authored a 300-page textbook, *Fundamentals of Ground Combat System Ballistic Vulnerability/Lethality* (soon to be distributed through SURVIAC). Dr. Deitz holds a B.A. in physics from Gettysburg College and an M.S. and a Ph.D. in electrical engineering from the University of Washington.

In receiving the Hollis award, Dr. Deitz joins a distinguished list of previous recipients, including Mr. Walt Hollis (2000), the Hon. Philip Coyle III (2001), Mr. G. Thomas Castino (2002), Mr. James Fasig (2003), Dr. Marion Williams (2004), the Hon. Thomas Christie (2005), RADM Bert Johnston (2006), and Mr. Jim O'Bryon (2007). ■

About the Author

Eric Edwards is technical writer/editor at the SURVICE Engineering Company in Belcamp, MD. He has supported ARL and other defense organizations for roughly 20 years, editing numerous technical publications, including Ballisticians in War and Peace, Volume III; Lessons Learned From Live Fire Testing; *and* Fundamentals of Ground Combat System Ballistic Vulnerability/Lethality. *Mr. Edwards holds a B.A. in print journalism from Bob Jones University and an M.S. in professional writing from Towson University.*

Tribute to Joe Hylan

"Joe Hylan was a friend to all in the survivability world and all who attended the NDIA Survivability Symposium knew him by his outstanding support."

—Dennis Lindell, Editor

This tribute was presented at the NDIA Survivability Symposium on 7 November 2007 by RADM Robert Gormley, USN (Ret).

Ladies and Gentlemen—Good morning. As some of you here already know, on Friday, 26 October, we lost a colleague and friend of aircraft survivability—Joe Hylan, NDIA's Operations Director—or staff representative—for the Combat Survivability Division. Joe, a young 55, suffered a fatal heart attack at Atlanta airport while returning from Panama City, FL, having completed his assigned mission for that week—running the annual NDIA Expeditionary Warfare conference there.

Joe Hylan was truly a unique individual. To know and work with him was to benefit from, and appreciate, the many fine qualities he possessed—integrity, loyalty, candor, good judgment, and a sharp focus on getting the job done. Joe was never one to complain about the hand that was dealt him or to blame others for misfortunes along the way. These attributes had their roots, I offer to you, in his earlier life in the Marine Corps, from which he retired some 13 years ago. Indeed, in civilian life Joe remained very much a Marine at his core.

To say Joe was taciturn is an understatement. He tended to keep his opinions to himself. But if he believed one's motivations were sincere, that reserve would soften and a natural sense of humor and grace would emerge.

Joe came to NDIA in the Spring 1997 just as the Combat Survivability Division was getting up to speed implementing a new policy of having symposiums at the same time every year, and in the same location. You know the line in the brochure—"If you are in the survivability business, the place to be is Monterey in November." Joe very quickly grasped what we wanted, was most supportive, and we came to depend on him in short order.

Although a staffer headquartered at NDIA in Washington, Joe's life as operations director was not an easy one. He shepherded seven dissimilar divisions, each of which held a symposium annually as well as some lesser events and a number of guidance board meetings each year. His "deployments," to use military jargon, were short but frequent, and always fraught with the challenges inherent in pulling off large scale events—some with up to 700 attendees—events involving varied community interests, technologies, and personalities. Yes, Joe managed a very diverse portfolio in addition to combat survivability—

- Science and engineering technology
- Targets and UAVs
- Technical information
- Homeland security
- Special operations and low intensity conflict
- Expeditionary warfare

Joe was tops at his trade, carefully balancing necessary association business considerations—like paying the bills to keep the wolf from the door—with satisfying the mission-related wishes of the volunteers in a given division, some of whom could be difficult to handle on occasion. "Herding cats" perhaps best describes this kind of exercise where, to be successful, a top flight association director must deal with folks from industry and government who are convinced they are right and absolutely must have this or that. Here, Joe was at his best—smoothing ruffled feathers, spurring those who might be lagging, and most importantly, anticipating needs and solving problems before most of us even knew one existed. And he possessed a characteristic many of us would do well to emulate—making division chairmen, such as I was for a number of years, as well as the annual symposium chairs, feel we were in control—in charge and running the show—when in fact the entire operation would have collapsed without his fine hand at the helm.

The photo above tells one a lot about Joe Hylan. Note the Marine Corps seal behind the left hand—clearly the Corps was never far from his mind. For me the photo brings to mind one of Joe's endearing qualities—his belief in the efficacy of what some call the horizontal filing system. Despite the appearance here of gross disorder, without fail Joe could always locate immediately whatever it was he was looking for. And that smile on his face is indicative of his attitude towards meeting the many challenges he faced day to day—always positive and upbeat, notwithstanding the crisis of the moment. Here, Joe's response to emergencies or the rantings of overanxious chairmen was almost universally, "Don't worry, sir, I'll take care of it." I can't tell you how many times he placated me with that phrase.

Finally, in remembering Joe I would like to share with you the words from the last four lines of the Marine Corps hymn:

"If the Army and the Navy
Ever look on Heaven's scenes,
They will find the streets are guarded
By United States Marines."

Joe Hylan was a Marine to the end, a friend, and valued colleague. We shall miss him. ■

About the Author

Rear Admiral Gormley, a former Naval Aviator, has been an advisor to the Joint Aircraft Survivability Program and its predecessor since 1985. He was a founding member of NDIA's Combat Survivability Division and served as its Chairman from 1988 through 2004.

Calendar of Events

JUL

35th International Pyrotechnics Seminar and Symposium
13–18 July 2008
Fort Collins, CO
http://www.ipsusa.org/index2.htm

SURVIAC Liaison Workshop
14-16 July 2008
Wright-Patterson AFB, OH
http://www.bahdayton.com/surviac/liaison2008.htm

JASP Summer PMSG
15–17 July 2008
St. Louis, MO

AUG

AIAA Modeling and Simulation Technologies Conference and Exhibit
18–21 August 2008
Honolulu, HI
http://aiaa.org/content.cfm?pageid=230&lumeetingid=1853#zz1855

2008 MSS Battlespace Acoustic and Magnetic Sensors (BAMS)
19–21 August 2008
https://www.sensiac.gatech.edu/external/mss/meetings/list_meetings.jsf

SEP

Tail Hook
4–7 September 2008
Reno, NV
http://www.tailhook.org

MODSIM World Conference 2008
16–18 September 2008
Virginia Beach, VA
http://www.modsimworld2007.com

JASP FY08 Joint Program Review
16–18 September 2008
Nellis AFB, NV

Vehicle Survivability Summit 2008: "Increasing Armour Strength and Reducing the IED Threat in Combat Theatres"
22–24 September 2008
Berlin, Germany
http://www.vssummit.com

OCT

MCAA
October 2008
Reno, NV
http://www.flymcaa.org

45th AOC Annual Convention
19–22 October 2008
Reno, NV
http://www.crows.org

2008 Combat Vehicles Conference
20–22 October 2008
Dearborn, MI
http://www.ndia.org/Template.cfm?Section=9620&Template=/ContentManagement/ContentDisplay.cfm&ContentID=22806

2008 TACOM Life Cycle Management Command Advanced Planning Briefing for Industry (TACOM LCMC APBI)
22–24 October 2008
Dearborn, MI
http://www.ndia.org/Template.cfm?Section=9520&Template=/ContentManagement/ContentDisplay.cfm&ContentID=23224

2008 MSS Missile Defense Sensors, Environments and Algorithms (MD-SEA)
27–30 October 2008
Contact SENSIAC for location information
https://www.sensiac.gatech.edu/external/mss/meetings/list_meetings.jsf

Aircraft Fire Protection and Mishap Investigation Course
27–31 October 2008
Miamisburg, OH
http://www.afp1fire.com/course.htm

NOV

NDIA Aircraft Survivability 2008
4–7 November 2008
Monterey, CA
http://www.ndia.org

JASP Winter JMUM
November 2008
Nellis AFB, NV

Information for inclusion in the Calendar of Events may be sent to:

SURVIAC, Washington Satellite Office
Attn: Christina McNemar
13200 Woodland Park Road, Suite 6047
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